

**SUGGESTED READINGS**

**SOURCES**

**GLOSSARY OF SCIENTIFIC TERMS:**

## References and Suggestions for Further Reading

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## Glossary of Scientific Terms

**Absolute zero.** The lowest possible temperature, about  $-273$  degrees Celsius, or 0 on the Kelvin scale.

**Acceleration.** A change in an object's speed or direction. See also *velocity*.

**Accelerator.** See *particle accelerator*.

**Amplitude.** The maximum height of a wave peak or the maximum depth of a wave trough.

**Anthropic principle.** Doctrine that one explanation for why the universe has the properties we observe is that, were the properties different, it is likely that life would not form and therefore we would not be here to observe the changes.

**Antimatter.** Matter that has the same gravitational properties as ordinary matter, but that has an opposite electric charge as well as opposite nuclear *force charges*.

**Antiparticle.** A particle of *antimatter*.

**ATB.** Acronym for "after the bang"; usually used in reference to time elapsed since the *big bang*.

**Atom.** Fundamental building block of matter, consisting of a *nucleus* (comprising *protons* and *neutrons*) and an orbiting swarm of *electrons*.

**Big bang.** Currently accepted theory that the expanding universe began some 15 billion years ago from a state of enormous energy, density, and compression.

**Big crunch.** One hypothesized future for the universe in which the current expansion stops, reverses, and results in all space and all matter collapsing together; a reversal of the *big bang*.

**Black hole.** An object whose immense gravitational *field* entraps anything, even light, that gets too close (closer than the black hole's *event horizon*).

- Black-hole entropy** The *entropy* embodied within a *black hole*.
- Boson.** A particle, or pattern of *string* vibration, with a whole number amount of *spin*; typically a *messenger particle*.
- Bosonic string theory.** First known string theory; contains *vibrational patterns* that are all *bosons*.
- BPS states.** Configurations in a *supersymmetric* theory whose properties can be determined exactly by arguments rooted in *symmetry*.
- Brane.** Any of the extended objects that arise in *string theory*. A one-brane is a *string*, a two-brane is a membrane, a three-brane has three extended dimensions, etc. More generally, a *p*-brane has *p* spatial dimensions.
- Calabi-Yau space, Calabi-Yau shape.** A space (shape) into which the extra spatial dimensions required by *string theory* can be *curled up*, consistent with the equations of the theory.
- Charge.** See *force charge*.
- Chiral, Chirality.** Feature of fundamental particle physics that distinguishes left- from right-handed, showing that the universe is not fully left-right symmetric.
- Closed string.** A type of *string* that is in the shape of a loop.
- Conifold transition.** Evolution of the *Calabi-Yau* portion of space in which its fabric rips and repairs itself, yet with mild and acceptable physical consequences in the context of *string theory*. The tears involved are more severe than those in a *flop transition*.
- Cosmic microwave background radiation.** Microwave radiation suffusing the universe, produced during the *big bang* and subsequently thinned and cooled as the universe expanded.
- Cosmological constant.** A modification of *general relativity's* original equations, allowing for a static universe; interpretable as a constant energy density of the vacuum.
- Coupling constant.** See *string coupling constant*.
- Curled-up dimension.** A spatial *dimension* that does not have an observably large spatial extent; a spatial dimension that is crumpled, wrapped, or curled up into a tiny size, thereby evading direct detection.
- Curvature.** The deviation of an object or of space or of *spacetime* from a *flat* form and therefore from the rules of geometry codified by Euclid.
- Dimension.** An independent axis or direction in space or *spacetime*. The familiar space around us has three dimensions (left-right, back-forth, up-down) and the familiar *spacetime* has four (the previous three axes plus the past-future axis). *Superstring theory* requires the universe to have additional spatial dimensions.

- Dual, Duality, Duality symmetries.** Situation in which two or more theories appear to be completely different, yet actually give rise to identical physical consequences.
- Electromagnetic field.** Force field of the *electromagnetic force*, consisting of electric and magnetic lines of force at each point in space.
- Electromagnetic force.** One of the four fundamental forces, a union of the electric and magnetic forces.
- Electromagnetic gauge symmetry.** *Gauge symmetry* underlying *quantum electrodynamics*.
- Electromagnetic radiation.** The energy carried by an *electromagnetic wave*.
- Electromagnetic wave.** A wavelike disturbance in an *electromagnetic field*; all such waves travel at the speed of light. Visible light, X rays, microwaves, and infrared radiation are examples.
- Electron.** Negatively charged particle, typically found orbiting the nucleus of an *atom*.
- Electroweak theory.** *Relativistic quantum field theory* describing the *weak force* and the *electromagnetic force* in one unified framework.
- Eleven-dimensional supergravity.** Promising higher-dimensional *supergravity* theory developed in the 1970s, subsequently ignored, and more recently shown to be an important part of *string theory*.
- Entropy.** A measure of the disorder of a physical system; the number of rearrangements of the ingredients of a system that leave its overall appearance intact.
- Equivalence principle.** See *principle of equivalence*.
- Event horizon.** The one-way surface of a *black hole*; once penetrated, the laws of gravity ensure that there is no turning back, no escaping the powerful gravitational grip of the black hole.
- Extended dimension.** A space (and *spacetime*) *dimension* that is large and directly apparent; a dimension with which we are ordinarily familiar, as opposed to a *curled-up dimension*.
- Extremal black holes.** *Black holes* endowed with the maximal amount of *force charge* possible for a given total mass.
- Families.** Organization of matter particles into three groups, with each group being known as a family. The particles in each successive family differ from those in the previous by being heavier, but carry the same electric and nuclear *force charges*.
- Fermion.** A particle, or pattern of *string* vibration, with half a whole odd number amount of *spin*; typically a matter particle.
- Feynman sum-over-paths.** See *sum-over-paths*.

**Field, Force field.** From a *macroscopic* perspective, the means by which a force communicates its influence; described by a collection of numbers at each point in space that reflect the strength and direction of the force at that point.

**Flat.** Subject to the rules of geometry codified by Euclid; a shape, like the surface of a perfectly smooth tabletop, and its higher-dimensional generalizations.

**Flop transition.** Evolution of the *Calabi-Yau* portion of space in which its fabric rips and repairs itself, yet with mild and acceptable physical consequences in the context of string theory.

**Foam.** See *spacetime foam*.

**Force charge.** A property of a particle that determines how it responds to a particular force. For instance, the electric charge of a particle determines how it responds to the *electromagnetic force*.

**Frequency.** The number of complete wave cycles a wave completes each second.

**Gauge symmetry.** *Symmetry* principle underlying the quantum-mechanical description of the three nongravitational forces: the symmetry involves the invariance of a physical system under various shifts in the values of *force charges*, shifts that can change from place to place and from moment to moment.

**General relativity.** Einstein's formulation of gravity, which shows that space and time communicate the gravitational force through their *curvature*.

**Gluon.** Smallest bundle of the *strong force field*; messenger particle of the strong force.

**Grand unification.** Class of theories that merge all three nongravitational forces into a single theoretical framework.

**Gravitational force.** The weakest of the four fundamental forces of nature. Described by Newton's universal theory of gravity, and subsequently by Einstein's *general relativity*.

**Graviton.** Smallest bundle of the *gravitational force field*; messenger particle for the gravitational force.

**Heterotic-E string theory (Heterotic  $E_8 \times E_8$  string theory).** One of the five *superstring theories*; involves closed strings whose right-moving vibrations resemble those of the *Type II string* and whose left-moving vibrations involve those of the *bosonic string*. Differs in important but subtle ways from the *Heterotic-O string theory*.

**Heterotic-O string theory (Heterotic  $O(32)$  string theory).** One of the five *superstring theories*; involves closed strings whose right-moving vibrations resemble those of the *Type II string* and whose left-moving vibrations involve those of the *bosonic string*. Differs in important but subtle ways from the *Heterotic-E string theory*.

**Higher-dimensional supergravity.** Class of *supergravity* theories in more than four *spacetime* dimensions.

**Horizon problem.** Cosmological puzzle associated with the fact that regions of the universe that are separated by vast distances nevertheless have nearly identical properties such as temperature. *Inflationary cosmology* offers a solution.

**Infinites.** Typical nonsensical answer emerging from calculations that involve *general relativity* and *quantum mechanics* in a point-particle framework.

**Inflation, Inflationary cosmology.** Modification to the earliest moments of the standard *big bang* cosmology in which universe undergoes a brief burst of enormous expansion.

**Initial conditions.** Data describing the beginning state of a physical system.

**Interference pattern.** Wave pattern that emerges from the overlap and the intermingling of waves emitted from different locations.

**Kaluza-Klein theory.** Class of theories incorporating extra *curled-up dimensions*, together with *quantum mechanics*.

**Kelvin.** A temperature scale in which temperatures are quoted relative to *absolute zero*.

**Klein-Gordon equation.** A fundamental equation of *relativistic quantum field theory*.

**Laplacian determinism.** Clockwork conception of the universe in which complete knowledge of the state of the universe at one moment completely determines its state at all future and past moments.

**Light clock.** A hypothetical clock that measures elapsed time by counting the number of round-trip journeys completed by a single *photon* between two mirrors.

**Lorentz contraction.** Feature emerging from *special relativity*, in which a moving object appears shortened along its direction of motion.

**Macroscopic.** Refers to scales typically encountered in the everyday world and larger; roughly the opposite of microscopic.

**Massless black hole.** In string theory, a particular kind of *black hole* that may have large mass initially, but that becomes ever lighter as a piece of the *Calabi-Yau* portion of space shrinks. When the portion of space has shrunk down to a point, the initially massive black hole has no remaining mass—it is massless. In this state, it no longer manifests such usual black hole properties as an *event horizon*.

**Maxwell's theory, Maxwell's electromagnetic theory.** Theory uniting electricity and magnetism, based on the concept of the *electromagnetic field*, devised by Maxwell in the 1880s; shows that visible light is an example of an *electromagnetic wave*.

**Messenger particle.** Smallest bundle of a *force field*; microscopic conveyer of a force.

**Mirror symmetry.** In the context of *string theory*, a *symmetry* showing that two different *Calabi-Yau shapes*, known as a mirror pair, give rise to identical physics when chosen for the *curled-up dimensions* of *string theory*.

**M-theory.** Theory emerging from the *second superstring revolution* that unites the previous five *superstring theories* within a single overarching framework. M-theory appears to be a theory involving eleven *spacetime dimensions*, although many of its detailed properties have yet to be understood.

**Multidimensional hole.** A generalization of the hole found in a doughnut to higher-dimensional versions.

**Multi-doughnut, Multi-handled doughnut.** A generalization of a doughnut shape (a torus) that has more than one hole.

**Multiverse.** Hypothetical enlargement of the cosmos in which our universe is but one of an enormous number of separate and distinct universes.

**Neutrino.** Chargeless species of particle, subject only to the *weak force*.

**Neutron.** Chargeless particle, typically found in the nucleus of an *atom*, consisting of three *quarks* (two down-quarks, one up-quark).

**Newton's laws of motion.** Laws describing the motion of bodies based on the conception of an absolute and immutable space and time; these laws held sway until Einstein's discovery of *special relativity*.

**Newton's universal theory of gravity.** Theory of gravity declaring that the force of attraction between two bodies is proportional to the product of their masses and inversely proportional to the square of the distance between them. Subsequently supplanted by Einstein's *general relativity*.

**Nonperturbative.** Feature of a theory whose validity is not dependent on approximate, *perturbative* calculations; an exact feature of a theory.

**Nucleus.** The core of an *atom*, consisting of *protons* and *neutrons*.

**Observer.** Idealized person or piece of equipment, often hypothetical, that measures relevant properties of a physical system.

**One-loop process.** Contribution to a calculation in *perturbation theory* in which one virtual pair of *strings* (or particles in a point-particle theory) is involved.

**Open string.** A type of *string* with two free ends.

**Oscillatory pattern.** See *vibrational pattern*.

**Particle accelerator.** Machine for boosting particles to nearly light speed and slamming them together in order to probe the structure of matter.

**Perturbation theory.** Framework for simplifying a difficult problem by finding an approximate solution that is subsequently refined as more details, initially ignored, are systematically included.

**Perturbative approach, Perturbative method.** See *perturbation theory*.

**Phase.** When used in reference to matter, describes its possible states: solid phase, liquid phase, gas phase. More generally, refers to the possible descriptions of a physical system as features on which it depends (temperature, *string coupling constant* values, form of *spacetime*, etc.) are varied.

**Phase transition.** Evolution of a physical system from one *phase* to another.

**Photoelectric effect.** Phenomenon in which *electrons* are ejected from a metallic surface when light is shone upon it.

**Photon.** Smallest packet of the *electromagnetic force field*; *messenger particle* of the *electromagnetic force*; smallest bundle of light.

**Planck energy.** About 1,000 kilowatt hours. The energy necessary to probe to distances as small as the *Planck length*. The typical energy of a vibrating *string* in *string theory*.

**Planck length.** About  $10^{-33}$  centimeters. The scale below which *quantum fluctuations* in the fabric of *spacetime* would become enormous. The size of a typical *string* in *string theory*.

**Planck mass.** About ten billion billion times the mass of a *proton*; about one-hundredth of a thousandth of a gram; about the mass of a small grain of dust. The typical mass equivalent of a vibrating *string* in *string theory*.

**Planck's constant.** Denoted by the symbol  $\hbar$ , Planck's constant is a fundamental parameter in *quantum mechanics*. It determines the size of the discrete units of energy, mass, *spin*, etc. into which the microscopic world is partitioned. Its value is  $1.05 \times 10^{-27}$  grams-cm/sec.

**Planck tension.** About  $10^{39}$  tons. The tension on a typical *string* in *string theory*.

**Planck time.** About  $10^{-43}$  seconds. Time at which the size of the universe was roughly the *Planck length*; more precisely, time it takes light to travel the *Planck length*.

**Primordial nucleosynthesis.** Production of atomic nuclei occurring during the first three minutes after the *big bang*.

**Principle of equivalence.** Core principle of *general relativity* declaring the indistinguishability of accelerated motion and immersion in a gravitational field (over small enough regions of observation). Generalizes the *principle of relativity* by showing that all observers, regardless of their state of motion, can claim to be at rest, so long as they acknowledge the presence of a suitable gravitational field.

**Principle of relativity.** Core principle of *special relativity* declaring that all constant-velocity observers are subject to an identical set of physical laws and that, therefore, every constant-velocity observer is justified in claiming that he or she is at rest. This principle is generalized by the *principle of equivalence*.

**Product.** The result of multiplying two numbers.

- Proton.** Positively charged particle, typically found in the nucleus of an *atom*, consisting of three *quarks* (two up-quarks and one down-quark).
- Quanta.** The smallest physical units into which something can be partitioned, according to the laws of quantum mechanics. For instance, *photons* are the quanta of the electromagnetic field.
- Quantum chromodynamics (QCD).** *Relativistic quantum field theory* of the *strong force* and *quarks*, incorporating *special relativity*.
- Quantum claustrophobia.** See *quantum fluctuations*.
- Quantum determinism.** Property of *quantum mechanics* that knowledge of the quantum state of a system at one moment completely determines its quantum state at future and past moments. Knowledge of the quantum state, however, determines only the probability that one or another future will actually ensue.
- Quantum electrodynamics (QED).** *Relativistic quantum field theory* of the *electromagnetic force* and *electrons*, incorporating *special relativity*.
- Quantum electroweak theory.** See *electroweak theory*.
- Quantum field theory.** See *relativistic quantum field theory*.
- Quantum fluctuation.** Turbulent behavior of a system on microscopic scales due to the *uncertainty principle*.
- Quantum foam.** See *spacetime foam*.
- Quantum geometry.** Modification of *Riemannian geometry* required to describe accurately the physics of space on *ultramicroscopic* scales, where quantum effects become important.
- Quantum gravity.** A theory that successfully merges *quantum mechanics* and *general relativity*, possibly involving modifications of one or both. *String theory* is an example of a theory of quantum gravity.
- Quantum mechanics.** Framework of laws governing the universe whose unfamiliar features such as *uncertainty*, *quantum fluctuations*, and *wave-particle duality* become most apparent on the microscopic scales of *atoms* and subnuclear particles.
- Quantum tunneling.** Feature of *quantum mechanics* showing that objects can pass through barriers that should be impenetrable according to Newton's classical laws of physics.
- Quark.** A particle that is acted upon by the *strong force*. Quarks exist in six varieties (up, down, charm, strange, top, bottom) and three "colors" (red, green, blue).
- Radiation.** The energy carried by waves or particles.
- Reciprocal.** The inverse of a number; for example, the reciprocal of 3 is  $\frac{1}{3}$ , the reciprocal of  $\frac{1}{2}$  is 2.
- Relativistic quantum field theory.** Quantum-mechanical theory of fields, such as the *electromagnetic field*, that incorporates *special relativity*.

- Resonance.** One of the natural states of oscillation of a physical system.
- Riemannian geometry.** Mathematical framework for describing curved shapes of any dimension. Plays a central role in Einstein's description of *spacetime* in *general relativity*.
- Schrödinger equation.** Equation governing the evolution of probability waves in *quantum mechanics*.
- Schwarzschild solution.** Solution to the equations of *general relativity* for a spherical distribution of matter; one implication of this solution is the possible existence of *black holes*.
- Second law of thermodynamics.** Law stating that total *entropy* always increases.
- Second superstring revolution.** Period in the development of *string theory* beginning around 1995 in which some *nonperturbative* aspects of the theory began to be understood.
- Singularity.** Location where the fabric of space or *spacetime* suffers a devastating rupture.
- Smooth. Smooth space.** A spatial region in which the fabric of space is flat or gently curved, with no pinches, ruptures, or creases of any kind.
- Space-tearing flop transition.** See *flop transition*.
- Spacetime.** A union of space and time originally emerging from *special relativity*. Can be viewed as the "fabric" out of which the universe is fashioned; it constitutes the dynamical arena within which the events of the universe take place.
- Spacetime foam.** Frothy, writhing, tumultuous character of the *spacetime* fabric on *ultramicroscopic* scales, according to a conventional point-particle perspective. An essential reason for the incompatibility of *quantum mechanics* and *general relativity* prior to *string theory*.
- Special relativity.** Einstein's laws of space and time in the absence of gravity (see also *general relativity*).
- Sphere.** The outer surface of a ball. The surface of a familiar three-dimensional ball has two dimensions (which can be labeled by two numbers such as "latitude" and "longitude," as on the surface of the earth). The concept of a sphere, though, applies more generally to balls and hence their surfaces, in any number of dimensions. A one-dimensional sphere is a fancy name for a circle; a zero-dimensional sphere is two points (as explained in the text). A three-dimensional sphere is harder to picture; it is the surface of a four-dimensional ball.
- Spin.** A quantum-mechanical version of the familiar notion of the same name; particles have an intrinsic amount of spin that is either a whole number or half a whole number (in multiples of *Planck's constant*), and which never changes.

**Standard model of cosmology.** *Big bang* theory together with an understanding of the three nongravitational forces as summarized by the *standard model of particle physics*.

**Standard model of particle physics, Standard model, Standard theory.** An enormously successful theory of the three nongravitational forces and their action on matter. Effectively the union of *quantum chromodynamics* and the *electroweak theory*.

**String.** Fundamental one-dimensional object that is the essential ingredient in *string theory*.

**String coupling constant.** A (positive) number that governs how likely it is for a given *string* to split apart into two strings or for two strings to join together into one—the basic processes in *string theory*. Each *string theory* has its own string coupling constant, the value of which should be determined by an equation; currently such equations are not understood well enough to yield any useful information. Coupling constants less than 1 imply that *perturbative methods* are valid.

**String mode.** A possible configuration (*vibrational pattern, winding configuration*) that a *string* can assume.

**String theory.** *Unified theory* of the universe postulating that fundamental ingredients of nature are not zero-dimensional point particles but tiny one-dimensional filaments called *strings*. String theory harmoniously unites *quantum mechanics* and *general relativity*, the previously known laws of the small and the large, that are otherwise incompatible. Often short for *superstring theory*.

**Strong force, Strong nuclear force.** Strongest of the four fundamental forces, responsible for keeping *quarks* locked inside *protons* and *neutrons* and for keeping protons and neutrons crammed inside of atomic nuclei.

**Strong force symmetry.** *Gauge symmetry* underlying the *strong force*, associated with invariance of a physical system under shifts in the color charges of *quarks*.

**Strongly coupled.** Theory whose *string coupling constant* is larger than 1.

**Strong-weak duality.** Situation in which a *strongly coupled* theory is *dual*—physically identical—to a different, *weakly coupled* theory.

**Sum-over-paths.** Formulation of *quantum mechanics* in which particles are envisioned to travel from one point to another along all possible paths between them.

**Supergravity.** Class of point-particle theories combining *general relativity* and *supersymmetry*.

**Superpartners.** Particles whose *spins* differ by 1/2 unit and that are paired by *supersymmetry*.

**Superstring theory.** *String theory* that incorporates *supersymmetry*.

**Supersymmetric quantum field theory.** *Quantum field theory* incorporating *supersymmetry*.

**Supersymmetric standard model.** Generalization of the *standard model of particle physics* to incorporate *supersymmetry*. Entails a doubling of the known elementary particle species.

**Supersymmetry.** A *symmetry* principle that relates the properties of particles with a whole number amount of *spin* (*bosons*) to those with half a whole (odd) number amount of *spin* (*fermions*).

**Symmetry.** A property of a physical system that does not change when the system is transformed in *some* manner. For instance, a *sphere* is rotationally symmetrical since its appearance does not change if it is rotated.

**Symmetry breaking.** A reduction in the amount of *symmetry* a system appears to have, usually associated with a *phase transition*.

**Tachyon.** Particle whose mass (squared) is negative; its presence in a theory generally yields inconsistencies.

**Thermodynamics.** Laws developed in the nineteenth century to describe aspects of heat, work, energy, *entropy*, and their mutual evolution in a physical system.

**Three-brane.** See *brane*.

**Three-dimensional sphere.** See *sphere*.

**Time dilation.** Feature emerging from *special relativity*, in which the flow of time slows down for an *observer* in motion.

**T.O.E. (Theory of Everything).** A quantum-mechanical theory that encompasses all forces and all matter.

**Topologically distinct.** Two shapes that cannot be deformed into one another without tearing their structure in some manner.

**Topology.** Classification of shapes into groups that can be deformed into one another without ripping or tearing their structure in any way.

**Topology-changing transition.** Evolution of spatial fabric that involves rips or tears, thereby changing the *topology* of space.

**Torus.** The two-dimensional surface of a doughnut.

**Two-brane.** See *brane*.

**Two-dimensional sphere.** See *sphere*.

**Type I string theory.** One of the five *superstring theories*; involves both *open* and *closed strings*.

**Type IIA string theory.** One of the five *superstring theories*; involves *closed strings* with left-right symmetric *vibrational patterns*.

**Type IIB string theory.** One of the five *superstring theories*; involves *closed strings* with left-right asymmetric *vibrational patterns*.

**Ultramicroscopic.** Length scales shorter than the *Planck length* (and also time scales shorter than the *Planck time*).



**Uncertainty principle.** Principle of *quantum mechanics*, discovered by Heisenberg, that there are features of the universe, like the position and *velocity* of a particle, that cannot be known with complete precision. Such uncertain aspects of the microscopic world become ever more severe as the distance and time scales on which they are considered become ever smaller. Particles and fields undulate and jump between all possible values consistent with the quantum uncertainty. This implies that the microscopic realm is a roiling frenzy, awash in a violent sea of *quantum fluctuations*.

**Unified theory, Unified field theory.** Any theory that describes all four forces and all of matter within a single, all-encompassing framework.

**Uniform vibration.** The overall motion of a *string* in which it moves without changes in shape.

**Velocity.** The speed and the direction of an object's motion.

**Vibrational mode.** See *vibrational pattern*.

**Vibrational pattern.** The precise number of peaks and troughs as well as their amplitude as a *string* oscillates.

**Vibration number.** Whole number describing the energy in the *uniform vibrational* motion of a *string*; the energy in its overall motion as opposed to that associated with changes in its shape.

**Virtual particles.** Particles that erupt from the vacuum momentarily; they exist on borrowed energy, consistent with the *uncertainty principle*, and rapidly annihilate, thereby repaying the energy loan.

**Wave function.** Probability waves upon which *quantum mechanics* is founded.

**Wavelength.** The distance between successive peaks or troughs of a wave.

**Wave-particle duality.** Basic feature of *quantum mechanics* that objects manifest both wavelike and particle-like properties.

**W bosons.** See *weak gauge boson*.

**Weak force, Weak nuclear force.** One of the four fundamental forces, best known for mediating radioactive decay.

**Weak gauge boson.** Smallest bundle of the *weak force field*; messenger particle of the *weak force*; called W or Z boson.

**Weak gauge symmetry.** *Gauge symmetry* underlying the *weak force*.

**Weakly coupled.** Theory whose *string coupling constant* is less than 1.

**Winding energy.** The energy embodied by a *string* wound around a circular *dimension* of space.

**Winding mode.** A *string* configuration that wraps around a circular spatial *dimension*.

**Winding number.** The number of times a *string* is wound around a circular spatial dimension.

**World-sheet.** Two-dimensional surface swept out by a *string* as it moves.

**Wormhole.** A tube-like region of space connecting one region of the universe to another.

**Z boson.** See *weak gauge boson*.

**Zero-dimensional sphere.** See *sphere*.