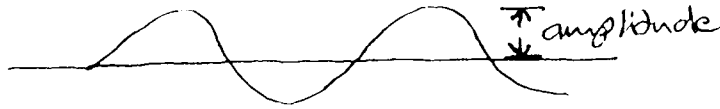


GLOSSARY

- acceleration** a change in velocity.
- action** mathematically, the integral $\int_{t_1}^{t_2} (KE - PE) dt$. That is, the time integral of the difference of kinetic and potential energies of an object in a force field. The **principle of least action** states that this quantity is always a minimum.
- amplitude** the potential difference between the peak and mean of a wave.



- In quantum mechanics, amplitude is the square root of the probability of finding a particle at a particular point in spacetime.
- anti-particle** a particle with electric charge opposite that of its partner particle but sharing all other characteristics. When antiparticle meets particle, the two annihilate.
- anti-shielding** the apparent increase in color force at increasing distance from a quark, caused by the presence of virtual gluons.
- astronomical unit** a unit of distance in astronomy: the distance from Earth to sun.
- atom** a nucleus (composed of protons and neutrons) surrounded by electrons. Chemical interactions of atoms are determined by the number of electrons (which in turn reflects the number of protons in the nucleus).
- baryon** a particle, such as the neutron or proton, composed of three quarks.
- Bell's inequality** mathematically
A prediction of classical physics regarding the detection of certain characteristics of particle/anti-particle pairs after their production at a common source. Tests of Bell's inequality support the predictions of quantum mechanics.
- big bang** the theoretical origin of the Universe. Evidence for a big bang includes the three-degree background radiation and cosmic expansion.
- black hole** a very large mass confined in a small volume such that the escape velocity exceeds the speed of light.
- boson** a particle that mediates a force; e.g. photon (electromagnetism), graviton (gravity), vector boson (weak force), and gluon (strong force).

Camouflage same as anti-shielding.

Cartesian coordinates a measuring grid based on mutually perpendicular (x and y) axes.

charge electric charge. A characteristic of particles that respond to the electromagnetic force. The electron carries an integer charge of -1; an up quark carries charge +2/3; and the down quark carries charge -1/3.

closed Universe term describing a Universe with enough mass to stop expanding and collapse back on itself.

cluster a physical association of stars (star cluster) or of galaxies (galaxy cluster). Generally, star clusters and galaxy clusters are gravitationally bound or had a common origin.

color the force binding quarks. Whimsically, the color force comes in red, green, and blue, and the net color of a hadron or meson is white.

color force another term for the strong force.

conservation laws statements that certain quantities such as charge, momentum, mass/energy, and angular momentum appear to be conserved (unchanged) in physical interactions.

constellation a visual association of stars in the night sky (such as the Big Dipper). The stars may or may not have any actual physical association.

cosmic string a theoretical extremely massive, infinitely long (or closed loop), thin string thought to have formed at domain boundaries in the very early Universe. Cosmic strings are a theoretical nidus for the formation of the superclusters of galaxies.

Coulomb force the electrostatic attraction or repulsion between two charged particles. This is one aspect of the electromagnetic force.

coupling the interaction of a boson with a fermion, e.g. the interaction of a photon with an electron.

curvature distortion in geometry. In spacetime, curvature is produced by mass.

degenerate pressure the resistance to further compression produced by electrons (in a white dwarf) or neutrons (in a neutron star) when the particles are squeezed to the lowest possible energy configuration by the local gravitational field.

degree 1. temperature scale.
2. angular measurement.

∇ (the del operator) symbol for gradient: the direction along which a quantity is changing most rapidly. e.g. on a hillside ∇ is the fall line.

derivative see differential.

differential the instantaneous rate of change of some quantity with respect to another (e.g. velocity is the differential of distance with respect to time, dx/dt). A **partial differential** is the instantaneous

rate of change of a quantity with respect to one variable among several which affect the quantity.

diffraction the apparent bending of a wave front around an obstacle.

diffraction grating an apparatus composed of a series of very fine lines which separates incident light (or other electromagnetic radiation) into an interference pattern or spectrum.

dimension any variable used in a geometric measurement (e.g. x , y , z , and t are the four dimensions of spacetime).

domain a region in the very early Universe that has undergone a phase transition while the surrounding region is still in the earlier phase. Domains may intersect at walls or lines or points.

dust in astronomy, macroscopic grains formed by aggregations of molecules.

elastic collision a collision between particles or macroscopic bodies in which kinetic energy is transferred perfectly, with no loss of energy to heat, noise, radiation, etc.

electromagnetism one of the four forces. Electromagnetism is mediated by the photon and affects all charged particles. As described by Maxwell's equations, electricity and magnetism are different manifestations of the same underlying force.

electron one of the fundamental particles, characterized by mass 0.51 MeV, charge -1 , spin $1/2$, and responding to all forces except the strong force.

electroweak force unification of the electromagnetic and weak forces which occurs at energies above about 180 GeV.

element an atom. The elements (e.g. carbon, hydrogen, oxygen, etc.) are classified according to their chemical properties, which, in turn, are determined by their electron configurations.

elementary particle strictly defined as a particle found in atoms -- e.g. the electron, proton, and neutron -- but more broadly referring to the fundamental particles -- leptons and quarks.

emission release of a photon during the transition of an electron from a higher to a lower energy state.

emission spectrum spectrum showing emission lines (bright lines) produced by electrons in excited atoms.

energy force times distance; or $mc^2 + 1/2mv^2$ (in special relativity); or hf (in quantum mechanics). Kinetic energy ($1/2mv^2$) is energy of motion. Potential energy (e.g. mgh) is energy of position.

event an occurrence in spacetime, measured in x , y , z , and t (e.g. the emission of a photon by an electron is an event).

Euclidean geometry in which parallel lines never intersect. There is no curvature in the coordinates of Euclidean geometry.

excitation promotion of a particle to a higher energy state by absorption of a photon or other interaction.

false vacuum energy state in the early Universe in which the overall energy was higher than the energy of the newly formed Higgs domains.

flat referring to a Euclidian Universe. A Universe with exactly enough mass/energy to balance the Universal expansion.

flavor a characteristic which differentiates particles of the same general class (e.g. up and down are two flavors of quark).

flux amount of something passing through a unit surface area per unit time (e.g. the neutrino flux at the Earth's surface is about $10^9/\text{cm}^2/\text{sec}$).

force interaction. That which causes an exchange of momentum or energy between particles or macroscopic objects or a change in the identity of a particle.

Fourier analysis mathematical analysis describing wave packets as the superposition of several pure frequencies.

frame of reference the coordinate system from which an experiment is performed or an observation made (e.g. an inertial frame or non-inertial frame).

frequency rate of oscillation, usually measured in cycles per second. Frequency is a property of waves.

fundamental particle a particle which (by current methods) is indivisible. The electron, neutrino, up quark, and down quark appear to be fundamental.

Galilean transformation the mathematical transformation of information from one reference frame to another frame moving at uniform relative velocity. The Galilean transformation involves simple addition of velocities.

gauge theory representation of a force as a distortion of local geometry.

general relativity Einstein's theory of gravity, incorporating spacetime and the metric.

geodesic the shortest distance between two points on a curved surface. In general relativity, the shortest spacetime interval between two events.

GeV one billion (giga) electron volts. A measure of energy used in high energy accelerator physics.

gravitation one of the four forces. All masses and energy respond to the gravitational force. It is mediated by the (theoretical) graviton.

graviton the theoretical boson which mediates the force of gravity.

group theory a mathematical theory relating things (such as

G Newton's
grav. constant

(particles) which share underlying characteristics (such as mass, charge, spin).

GUT grand unified theory. The description of the strong, weak, and electromagnetic forces (excluding gravity) as manifestations of the same underlying Force.

Higgs field a primordial field which developed at the freezing of the strong force from the electroweak force in the very early Universe. The energy of a Higgs field is lower than the energy of the surrounding "false vacuum."

Higgs particle the particle associated with the Higgs field (just as the photon is associated with the electromagnetic field).

Hubble constant the numerical value for the rate of recession of the galaxies, currently estimated at between 50 and 100 km/sec/Megaparsec.

Hubble law the observation that the galaxies are receding from each other at rates proportional to their distance.

identity element the procedure (I) in group theory which when added to another procedure P gives P. By group notation, $I + P = P$

induction production of an electric current by a magnetic field.

inertia a property of mass. Because of inertia, a mass resists acceleration.

inertial reference frame a frame of reference moving at uniform velocity.

inflation an episode of rapid expansion in the early Universe.

infrared that part of the electromagnetic spectrum of wavelengths about 10^{-3} to 10^{-6} m (slightly longer than visible light). We feel infrared radiation as heat.

isospin a characteristic of particles, specifically of quarks and hadrons. Isospin distinguishes the class of baryons from other particles: protons and neutrons have the same isospin.

joule a measure of energy: one newton-meter.

Kelvin scale temperature scale based on absolute zero using the same degree intervals as the centigrade scale.

Kepler's laws laws of planetary motion. See p.1

(**kinetic energy** energy of motion. $KE = 1/2 mv^2$. That is, the kinetic energy of an object is one-half the product of its mass and the square of its velocity.

lepton a subclass of fermions. Leptons include all fermions not composed of quarks (and therefore not responding to the strong force). Electrons and neutrinos are the common leptons.

light year a measure of distance -- the distance light travels in one year.

local curvature spacetime curvature in the vicinity of a mass.

local geometry geometry in the immediate vicinity of the event under consideration.

Lorentz transformation the mathematical formulas describing changes in time, length, and mass of objects moving at high relative velocities. (e.g. $l' = l \sqrt{1 - v^2/c^2}$)

mass measurement of quantity of matter, characterized by inertia. Mass and energy are inter-related by $E = mc^2$.

mass/energy a term acknowledging the equivalence of mass and energy ($E = mc^2$), often used in describing the total mass and energy in a system.

matter structural substance in the Universe, composed of fermions.

mechanics in physics, the study of the interactions of macroscopic (large) objects.

mega- prefix meaning one million (10^6) (e.g. a megaparsec is one million parsecs.)

metric Einstein's method of measuring spacetime curvature (hence the gravitational field). The metric has ten components which depend on mass, mass flux, and momentum flux through local spacetime.

momentum mass times velocity. (In quantum mechanics, momentum is h/λ .) Momentum is a conserved quantity.

nano- prefix meaning one one-billionth (10^{-9}) (e.g. a nanosecond is one one-billionth of a second.)

neutron a baryon composed of two down quarks and one up quark.

neutron star a stage of evolution of stars of mass greater than about 1.5 solar masses. Neutron stars result from the coalescence of electrons and protons under tremendous gravitational pressure. Many neutron stars are pulsars.

newton a measure of force. One newton is the force giving an acceleration of 1 m/sec^2 to a mass of one kg.

Newton's laws in physics, the classical laws of mechanics and gravitation. See Ch. 1

non-inertial reference frame an accelerating reference frame. General relativity describes physical measurements in non-inertial frames.

ohm the unit of electrical resistance.

Oort cloud region beyond Pluto thought to contain debris largely unchanged since the origin of the solar system. Comets originate in the Oort cloud.

parity a property of certain events that they appear the same even when mirror-reversed. The weak interaction violates parity.

parsec "parallax-second," a unit of astronomical measurement. The distance to a star that appears to move one arc-second of parallax from a baseline of one astronomical unit. A parsec equals about 3.4 light years.

particles the constituents of matter and the carriers of force. The fundamental particles include

fermions

electron
neutrino
up quark
down quark

bosons

photon
graviton
vector boson
gluon

phase the stage of a wave cycle at which the wave is measured. If two waves are "in phase" they are at the same stage of their cycle at the same time.



waves in phase

photon a boson. The carrier of the electromagnetic force and the particle equivalent to electromagnetic radiation (e.g. light). Photons have zero rest mass and always move at the speed of light.

Planck's constant (h) the quantum unit of action. Planck's constant represents the quantum nature of matter and energy -- that they come in discrete packets.

potential energy energy of position. (e.g. the potential energy of a mass raised to height h above the surface of Earth is mgh , where g is the gravitational acceleration at the Earth's surface.)

proton a baryon composed of two up quarks and one down quark.

pulsar an astronomical object which emits regular pulses of electromagnetic radiation. Pulsars are thought to be spinning neutron stars.

QCD quantum chromodynamics. The theory describing the strong (color) force (the rules of quark interaction).

QED quantum electrodynamics. The quantum description of the interactions of light and matter.

quantum mechanics the laws describing the interactions of the very smallest bits of matter and energy.

quark one of the fundamental particles. Quarks carry fractional electric charge (e.g. $+2/3$ or $-1/3$) and respond to all the forces, including the strong force.

quasar an extremely powerful astronomical object, usually very distant (approaching the limits of observation.) Quasars are thought to be energetic galactic nuclei, perhaps powered by black holes.

radioactivity the emission of particles and energy (e.g. alpha and beta particles and gamma rays) from unstable atomic nuclei.

refraction change in velocity of a wave when it passes into a different medium (e.g. light slows when it enters glass). The change in velocity effectively "bends" the direction of wave travel.

resolution the smallest dimension observable by a particular apparatus. Resolution depends on the wavelength of the probe beam (e.g. an electron microscope, in which the probe electrons have wavelengths shorter than visible light, can resolve smaller structures than can light microscopes.)

resonance in particle physics, a particle with characteristics (such as charge and spin) similar to a fundamental particle but with higher energy (hence more mass). Resonances exist for a only an instant before disintegrating to fundamental particles.

rishon theory a theory which postulates smaller particles called rishons as the components of leptons and quarks.

scattering "bouncing" a probe particle off a target particle in an accelerator. The scattering angle is the angle at which the probe particles recoil measured relative to their original momentum vector.

shielding apparent diminution of the charge of an electron (or other charged particle) caused by the presence of virtual particles around the "real" electron.

smoothness in cosmology, the measure of the distribution of mass/energy in the Universe. A perfectly smooth Universe would have uniform distribution of mass/energy.

spacetime the coordinates used to measure events in the Universe: three space variables (x, y, and z) and one of time. Spacetime can be regarded as the "fabric" of the Universe.

spin a characteristic of particles. Spin "1/2" indicates a particle can spin in one of two directions.

special relativity the theory (experimentally verified) describing changes in our measurements of mass, length, and time required to describe physical systems moving at high velocity in inertial reference frames.

spectrum the pattern of electromagnetic radiation produced by splitting an incident beam with a prism or diffraction grating. A spectrum displays the components of the incident radiation.

string a theory describing the fundamental particles as one-dimensional string segments. Not the same as cosmic strings.

supercluster the largest-scale structure of mass/energy yet identified in the Universe. A supercluster consists of many clusters of galaxies and may extend for hundreds of millions of light years across the cosmos.

symmetry the concept that an operation performed on a physical system produces no observable change in the system (e.g. mirror reflection of a collision between billiard balls shows no difference in momentum transfer).

tensor a geometric shape defined by a set of vectors. Tensors can be used to map spacetime and the distortion of spacetime produced by mass. See p.58

transformation a mathematical modification used to define events in one coordinate system (e.g. a moving system) as seen from another coordinate system. The Galilean transformation simply adds velocities, while the Lorentz transformation includes a term $(\sqrt{1 - v^2/c^2})$ defining relativistic changes in mass, length, and time.

uncertainty principle in quantum mechanics, a statement that we cannot know precisely, at the same time, both the momentum and location of a particle. $\Delta x \Delta p \geq \hbar$

vacuum the state of lowest possible mass/energy. By the laws of quantum mechanics, virtual particles are present even when all other mass/energy has been evacuated.

variable a symbol in an algebraic statement which can take on any value, depending on the physical system under consideration (e.g. in Newton's law of gravity ($F = GMm/R^2$), M , m , and R are the variables which define the force of gravity between two objects).

vector any value with a direction as well as a numerical amplitude (e.g. velocity, acceleration, and momentum are all vector quantities).

velocity the time rate of change of distance (dx/dt). Velocity is a vector quantity, i.e. it has a direction as well as speed.

virtual particles particle/anti-particle pairs which flash

in and out of existence faster than they can be detected. Their existence follows from the time/energy statement of the uncertainty principle ($\Delta E \Delta t \geq h$).

wave any physical system which exhibits periodic motion and which travels (e.g. water waves, light, and sound).

wavelength the distance between crests of a wavetrain. Symbolized λ .

wavenumber the number of waves per unit distance. Wavenumber is proportional to frequency.

wave packet a short pulse of waves defining a particle. Wave packets can be analyzed and described by Fourier analysis. See p.96

wavetrain a sample composed of a few waves taken from a larger series (e.g. electromagnetic waves sampled from light traveling across the Universe).

white dwarf an evolutionary stage of stars about the mass of the sun. Atoms in the star are compressed by gravity such that electrons occupy the lowest possible energy levels, and further collapse is resisted by degenerate electron pressure.

work force applied over a distance. Work is defined in the same terms as energy (force times distance).

X particles theoretical bosons which mediate the strong/electroweak force (the unification of the strong, weak, and electromagnetic forces). X particles theoretically swap flavors between quarks and leptons and thus interconvert all the fermions. They are produced only at energies exceeding 10^{19} GeV in conditions thought to exist in the very early Universe.

SYMBOLS

a acceleration

α alpha, as in alpha particle (helium nucleus)

B electric field

β beta, as in beta particle (electron)

c speed of light (about 300000 km/sec)

C degrees centigrade (each degree is one one-hundredth the temperature difference between the freezing point and boiling point of water.)

cm centimeter

d distance. Also the symbol for the down quark.

Δ delta. The change in, or amount of uncertainty in, a measurement.

∇ the del operator. Gradient.

dx/dt a differential expressing the instantaneous change in x (distance) with respect to time.

$\partial x/\partial t$ a partial differential expressing the differential of x with respect to time when there are other variables besides t that affect x .

E energy

ϵ a convenient constant used in electromagnetism having dimensions coulomb²/N-m²

γ gamma. Symbol for photon.

f frequency. Other texts sometimes use the symbol ν for frequency.

F force

g gravity. Also the symbol for the acceleration due to gravity at the Earth's surface (about 10 m/sec²).

G the gravitational constant, having a value about 6.67×10^{-11} N-m²/sec²

gm gram (unit of mass)

h Planck's constant, having a value about 6.63×10^{-34} J-sec. Also used as a symbol for height.

J joule (a measure of energy).

j electric current

K degrees of temperature on the Kelvin scale. Same temperature intervals as the centigrade scale, but based at absolute zero.

KE kinetic energy

kg kilogram (one thousand grams)

kilo prefix meaning one thousand

l length

λ lambda, symbol for wavelength
l.y. light year

m mass. Also the symbol for meter, the standard measure of length.

N Newton, a measure of force.

ν nu, symbol for neutrino. Sometimes used in other texts as a symbol for frequency.

Ω (capital) omega, symbol for the ratio of the actual mass of the Universe to the mass needed for closure.

ω omega, symbol for angular velocity

p momentum

PE potential energy

π pi, the ratio of the circumference of a circle to its diameter (about 3.14159)

q electric charge

R radius

ρ rho, symbol for density (e.g. charge density or mass density) enclosed by a surface

Σ sigma, symbol for summation

\int integral. Summation over a certain interval.

sec second

Θ theta, symbol for angle

t time

u often used to symbolize a component of velocity. Also the symbol for the up quark.

v velocity

= equals

\geq greater than or equal to

\leq less than or equal to

≈ approximately equal to

✓ power symbol (e.g. 10^{12} is ten squared)