# Glossary of MRI Terms

# A

**Absorption mode.** Component of the MR signal that yields a symmetric, positive-valued *line shape*.

**Acceleration factor**. The multiplicative term by which faster imaging pulse sequences such as *multiple echo imaging* reduce total imaging time compared to conventional imaging sequences such as *spin echo imaging*.

**Acoustic noise.** Vibrations of the *gradient coil* support structures create sound waves. These vibrations are caused by interactions of the *magnetic field* created by pulses of the current through the gradient coil with the main magnetic field in a manner similar to a loudspeaker coil. Sound pressure is reported on a logarithmic scale called sound-pressure level expressed in *decibels (dB)* referenced to the weakest audible 1,000 Hz sound pressure of $2x10^{-5}$ pascal. Sound level meters contain filters that simulate the ear's frequency response. The most commonly used filter provides what is called A weighting, with the letter A appended to the dB units, i.e., dBA.

**Acquisition matrix.** Number of independent data samples in each direction, e.g., in 2*DFT* imaging it is the number of samples in the phase-encoding and frequency-encoding directions, and in *reconstruction from projections* imaging it is the number of samples in time and angle. The acquisition matrix may be asymmetric and of different size than the reconstructed image or display matrix, e.g., with *zero filling* or interpolation, or (for asymmetric sampling) by exploiting the symmetry of the data matrix. For symmetric sampling, the acquisition matrix will roughly equal the ratio of image field of view to *spatial resolution* along the corresponding direction (depending on *filtering* and other processing).

**Acquisition Time.** See *Image acquisition time.*

**Acquisition window.** Time in the MR *pulse sequence* during which the MR signal is recorded. The duration can be denoted *TAD* (for "time of *analog to digital conversion*").

**Active shielding.** *Magnetic shielding* through the use of secondary shielding *coils* designed to produce a magnetic field that cancels the field from primary coils in regions where it is not desired, e.g., outside the bore of the magnet. These active shielding coils may be located inside the magnet *cryostat*. Active shielding can be applied to the main magnet or to the *gradient magnetic fields*. See also *Magnetic shielding*, *self-shielding*, and *room shielding*.

**Active shimming.** *Shimming* is the process of making the magnetic field more uniform by suitably adjusting the currents in *shim coils.*

**ADC.** See *Analog to digital converter.*

**Adiabatic fast passage (AFP).** Technique of producing rotation of the *macroscopic magnetization vector* by sweeping the *frequency* of an irradiating *RF* wave (or the strength of the *magnetic field*) through *resonance* (the *Larmor frequency*) in a time short compared to the *relaxation times*. Particularly used for *inversion* of the *spins*. A *continuous wave MR* technique.

**Adiabatic rapid passage**. See *Adiabatic fast passage.*

**AFP**. See *Adiabatic fast passage.*

**Aliasing**. Consequence of *sampling* the MR signal in which any components of the signal that are at a higher *frequency* than the *Nyquist limit* will be "folded" in the *spectrum* so that they appear to be at a lower frequency. In *Fourier transform imaging* this can produce an apparent wrapping around to the opposite side within the image of a portion of the object that extends beyond the edge of the reconstructed region.

**Analog to digital converter (ADC)**. Part of the *interface* that converts ordinary (analog) signals, such as the current in an MR receiver coil, into a digital number form, that can be stored and read by the *computer*. Also commonly termed digitizer.

**Angiography**. Application of MRI to produce images of blood vessels, for example with *flow effect* or *relaxation time* differences. Some common approaches use the washout of *saturated spins* from a region by blood flow to increase the relative intensity of blood vessels within images or use the variable sensitivity to motion-induced *phase* shifts provided by adjusting *gradient moments* to discriminate against the signal from stationary tissue.

**Angular frequency (ω)**. *Frequency* of oscillation or rotation (measured, e.g., in radians/second) commonly designated by the Greek letter omega: $\omega = 2\pi f$, where f is frequency in *hertz* (Hz).

**Angular momentum**. A *vector* quantity given by the vector product of the momentum of a particle and its position vector. In the absence of external forces, the angular momentum remains constant, with the result that any rotating body tends to maintain the same axis of rotation. In the presence of a *torque* applied to a rotating body in such a way as to change the direction of the rotation axis, the resulting change in angular momentum results in *precession*. Atomic nuclei possess an intrinsic angular momentum referred to as *spin*, measured in multiples of Planck's constant.

**Annotation**. A description of the factors used in creating an MR image. Appropriate annotation should include the type and times of the *pulse sequence*, the number of signals averaged or added (*NSA*), the size of the reconstructed region, the size of the *acquisition matrix* in each direction, and the *slice thickness*.

**Antenna**. Device to send or receive electromagnetic radiation. In the MR context, it is preferable to think of fields rather than electromagnetic radiation, as it is the magnetic vector alone that couples the *spins* and the *coils*, and the term coil should be used instead.

**Apodization**. Multiplication of acquired MR data by a function smoothly tapering off at higher *spatial frequencies* so as to reduce "ringing" *artifacts* near edges in the corresponding image or spectrum due to *truncation* and *Gibbs phenomenon*. It is a form of *filtering*.

**Array coil**. *RF coil* composed of multiple separate elements that can be used individually (*switchable coil*) or used simultaneously. When used simultaneously, the elements can either be: 1) electrically coupled to each other ("*coupled array coils*"), through common transmission lines or mutual *inductance*, or 2) electrically isolated from each other ("*isolated array coils*"), with separate transmission lines and *receivers* and minimum effective mutual inductance, and with the signals from each transmission line processed independently or at different *frequencies*.

**Array processor**. Optional component of the *computer* system specially designed to speed up numerical calculations like those needed in *MR imaging*.

**Artifacts**. False features in the image produced by the imaging process. The random fluctuation of intensity due to *noise* can be considered separately from artifacts.

**Asymmetric sampling.** The collection of more data points on one side of the k-space origin than on the other. With fewer k-space data points prior to the center (echo) a shorter echo time can be attained. Asymmetric acquisition in any phase encoding direction followed by partial-Fourier reconstruction leads to a reduction in imaging time.

**Attenuation**. Reduction of power, e.g., due to passage through a medium or electrical component. Attenuation in electrical systems is commonly expressed in *dB*.

**Attenuator.** Device which reduces a signal by a specific amount, commonly given in *dB*.

**Axial plane.** See *Transverse plane* or *transaxial plane*.

**Autotuning.** A means for optimizing the *tuning* and *matching* of *RF coils* under different loading conditions without operator intervention. For large, high-power coils such as body coils, autotuning involves the adjustment of variable capacitors using electric or hydraulic motors. For low power coils, the tuning elements are most often variable capacitance diodes (varactors) fed by a *computer*-generated variable voltage.

# B

**$B_o$**. A conventional symbol for the constant *magnetic (induction) field* in an *MR system*. (Although historically used, $H_o$ (units of *magnetic field* strength, ampere/meter) should be distinguished from the more appropriate $B_o$ [units of magnetic induction, *tesla*].)

**$B_1$**. A conventional symbol for the *radiofrequency magnetic* induction field used in an MR system (another symbol historically used is $H_1$). It is useful to consider it as composed of two oppositely rotating *vectors*, usually in a plane transverse to $B_o$. At the *Larmor frequency*, the vector rotating in the same direction as the *precessing spins* will interact strongly with the spins.

**BOLD.** See *Blood oxygen level dependent effect*.

**Balanced gradient.** A gradient waveform which will act on any stationary spin on resonance between two consecutive RF pulses and return it to the same phase it had before the gradients were applied.

**Balanced steady-state free precession.** An MR *gradient echo pulse sequence* designed to produce contrast weighted by the T2/T1 ratio, with higher SNR and reduced artifacts compared to *SSFP*. Typically, TR is set to be as short as possible (short compared to the T2 values of the tissues of interest), TE is intermediate (approximately TR/2), and a flip angle of $45^o$ to $90^o$ is used to result in T2/T1-weighted SSFP images. Balanced SSFP sequences use specific “balanced” gradients to return the magnetization to the same phase it had before the gradients were applied, thus increasing signal and reducing artifacts. Specific vendor names for this sequence include True-Flash imaging with steady-state precession (True-FISP), fast imaging employing steady-state acquisition (FIESTA), and balanced fast-field echo (balanced-FFE). See *Steady-state free precession*.

**Bandwidth**. A general term referring to a range of *frequencies* (e.g., contained in a signal or passed by a signal processing system).

**Baseline**. A generally smooth background curve with respect to which either the *integrals* or peak heights of the *resonance spectral lines* in the *spectrum* are measured.

**Baseline correction**. Processing of the *spectrum* to suppress *baseline* deviations from zero that may be superimposed on desired *spectral lines*. These deviations may be due either to various instrumental effects or to very broad spectral lines.

**Bilateral imaging.** For symmetric anatomic features, such as breasts or temperomandibular joints (TMJ), imaging of both organs or anatomic features in the same imaging session.

**Birdcage coil**. An *RF* volume *coil* designed to produce a homogeneous $B_1$ field by using multiple parallel conductors symmetrically spaced around the surface of a cylinder, connected by end rings. These are turned into low pass or high pass filter sections by adding capacitors in each conductor, or between each conductor in the end rings, so that at resonance there is a resulting homogeneous $B_1$ field. When the $B_1$ field is circularly polarized, the structure can be used as a *quadrature coil*.

**Bloch equations**. Phenomenological “classical” equations of motion for the *macroscopic magnetization vector*. They include the effects of *precession* about the *magnetic field* (static and RF) and the *T1* and *T2 relaxation times*.

**Blood oxygen level dependent effect (BOLD)**. A change in MRI-measurable signal caused by changes in the amount of oxygenated hemoglobin available in the venous circulation of the brain. Oxygenated hemoglobin has a smaller magnetic susceptibility than deoxygenated hemoglobin. Neural activity causes replacement of deoxygenated hemoglobin by oxygenated hemoglobin, which has higher T2* due to its smaller magnetic susceptibility. As T2* increases, higher signal is measured on T2*-weighted gradient-echo images, yielding a positive signal of increased venous circulation.

**Bolus tracking.** A method of tracking moving spins after tagging them (locally altering their magnetization). The moving spins are then imaged at some time after tagging to see where the bolus (the small tagged volume of spins) has moved in the imaging plane.

**Boil off rate**. Rate of *cryogen* evaporation in *superconducting magnets*, usually measured in liters of liquid per hour. It increases during *ramping* of the magnet and with *eddy currents* induced in the cryoshields by pulsed field gradients. In calculating cryogen consumption additional transfer and filling losses have to be considered.

**Boltzmann distribution**. If a system of particles which are able to exchange energy in collisions is in thermal equilibrium, then the relative number (*population*) of particles, $N_1$ and $N_2$, in two particular *energy levels* with corresponding energies, $E_1$ and $E_2$, is given by

$$N_1/N_2 = \exp[-(E_1 - E_2)/kT]$$

where k is Boltzmann's constant and T is absolute temperature. For example, in *MR* of protons at room temperature in a *magnetic field* of 0.25 *tesla*, the difference in relative numbers of spins aligned with the magnetic field and against the field is about one part in a million; the small excess of nuclei in the lower energy state is the basis of the net *magnetization* and the *resonance* phenomenon.

# C

**CBF.** See *Cerebral blood flow.*

**CBV.** See *Cerebral blood volume*.

**Cardiac gating**. See *Gating* and *Synchronization*, *cardiac.*

**Cardiac phase.** A particular point in the cardiac cycle.

**Carr-Purcell (CP) sequence**. Sequence of a *90° RF pulse* followed by repeated 180° RF pulses to produce a train of *spin echoes*; is useful for measuring *T2*.

**Carr-Purcell-Meiboom-Gill (CPMG) sequence**. Modification of *Carr-Purcell RF pulse sequence* with 90° *phase* shift in the *rotating frame of reference* between the 90° pulse and the subsequent 180° pulses in order to reduce accumulating effects of imperfections in the 180° pulses. Suppression of effects of pulse error accumulation can alternatively be achieved by switching phases of the 180° pulses by 180°.

**Cerebral blood flow (CBF).** The flow of capillary blood through the cortex, measured in units of flow (milliliters per minute) per unit mass of cortex.

**Cerebral blood volume (CBV).** The volume of blood in a given volume of cerebral cortex, measured in units of volume.

**Chemical shift (δ)**. The change in the *Larmor frequency* of a given nucleus when bound in different sites in a molecule, due to the magnetic shielding effects of the electron orbitals. Chemical shifts make possible the differentiation of different molecular compounds and different sites within the molecules in high-resolution MR spectra. The amount of the shift is proportional to magnetic field strength and is usually specified in parts per million (ppm) of the resonance frequency relative to a standard. The actual frequency measured for a given *spectral line* may depend on environmental factors such as effects on the local magnetic field strength due to variations of *magnetic susceptibility*.

**Chemical shift artifact**. See *Chemical shift spatial offset.*

**Chemical shift imaging**. A magnetic resonance imaging technique that provides mapping of the regional distribution of intensity (images) of a specific range of *chemical shifts*, corresponding to individual *spectral lines* or groups of lines. The chemical shift can be treated as an additional dimension to be reconstructed. For example, all spatial dimensions can be encoded with *phase encoding* prior to signal acquisition and the signal then acquired in the absence of *magnetic field gradients*; recovery of spatial and chemical shift dimension can be achieved by appropriate *Fourier transformation* of the resulting data set.

**Chemical shift reference**. A compound with respect to whose *frequency* the chemical shifts of other compounds can be compared. The standard can either be internal or external to the sample. Because of the need for possible corrections due to differential magnetic susceptibility between an external standard and the sample being measured, the use of an internal standard is generally preferred.

**Chemical shift spatial offset**. Image *artifact* of apparent spatial offset of regions with different chemical shifts along the direction of the *frequency encoding gradient*; a similar effect may be found in the *slice* selection direction.

**Cine acquisition.** The collection of images (usually at the same spatial location) covering one full period of motion or change, but which may be acquired over several periods to obtain complete coverage.

**C/N**. See *Contrast-to-noise ratio.*

**Circularly polarized coil**. A coil designed to excite or detect spins using two orthogonal transmit and/or receive channels. As a transmitter coil, there is a factor of 2 reduction in power required. It theoretically yields a x2 improvement in SNR over a linearly polarized coil as a receiving coil.

**CNR**. See *Contrast-to-noise ratio.*

**Coherence**. Maintenance of a constant *phase* relationship between rotating or oscillating waves or objects. Loss of phase coherence of the *spins* results in a decrease in the *transverse magnetization* and hence a decrease in the *MR signal*. In the quantum mechanical description of magnetic resonance, coherence refers to a transition between different states of the spin system (see *multiple quantum coherence*).

**Coherent**. A state of a spin sample in which all spins in a voxel are in-phase.

**Coil**. Single or multiple loops of wire (or other electrical conductor, such as tubing, etc.) designed either to produce a *magnetic field* from current flowing through the wire, or to detect a changing magnetic field by voltage induced in the wire.

**Coil loading**. In MR imaging, the interaction of the patient with the RF coil, which causes shifts of the *resonance frequency* and damping of the coil's resonance and hence reduction of the *quality factor* because of magnetic induction and dielectric losses in the patient.

**Complex conjugate**. An operation on a complex number which negates the sign of the imaginary component of a complex vector. The two vectors then form a complex-conjugate pair.

**Composite excitation.** Excitation of tissue created by a series of pulses rather than by a single radiofrequency pulse. The purpose of composite excitation is usually for the sum of these to produce net excitation of a target tissue, but for phase variations during the intervals between pulses to cause destructive interference, and therefore cause little or no excitation, of undesired tissue. Applications include selective excitation of water, or of tissues not subject to magnetization transfer.

**Continuous wave NMR (CW)**. A technique for studying *NMR* by continuously applying *RF* radiation to the sample and slowly sweeping either the *RF frequency* or the *magnetic field* through the *resonance* values; now largely superceded by *pulse MR* techniques.

**Contrast**. In conventional radiography, contrast is defined as the difference of the signal intensities divided by the average signal intensity in two adjacent regions. In a general sense, we can consider image contrast, where the strength of the image intensity in adjacent regions of the image is compared, or object contrast, where the relative values of a parameter affecting the image (such as *spin density* or *relaxation time*) in corresponding adjacent regions of the object are compared. Relating image contrast to object contrast is more difficult in MR *imaging* than in conventional radiography, as there are more object parameters affecting the image and their relative contributions are very dependent on the particular imaging technique used. As in other kinds of imaging, image contrast in MRI will also depend on region size, as reflected through the modulation transfer function (MTF) characteristics. The contrast between an object (e.g., lesion) and the background will also depend on the particular choice of designated background (e.g., fat, muscle, etc.).

**Contrast agent**. Substance administered to subject being imaged to alter selectively the image intensity of a particular anatomical or functional region, typically by altering the *relaxation times,* including T1, T2, and T2*.

**Contrast-to-noise ratio**. Ratio of the absolute difference in intensities between two regions to the level of fluctuations in intensity due to *noise*.

**Convolution differencing**. A method of suppressing broad underlying *spectral lines* in order to emphasize narrower spectral lines. Strong smoothing of the spectrum (e.g., by severe negative *exponential weighting* of the time data) will suppress the narrow lines but minimally affect very broad ones; subtracting such a smoothed spectrum from the original will largely remove the contributions from the broad lines. This provides a means of *baseline correction*.

**Coronal plane.** The plane defined by the head-to-foot and left-to-right directions in the human body. A stack of images acquired in the coronal plane separates images by their anterior-to-posterior locations. See also *Orientation*.

**Correlation time**. The characteristic time between significant fluctuations in the local magnetic field experienced by a spin due to molecular motions. For values of the correlation time such that the magnetic field as a function of time has large *Fourier* components near the resonance frequency, the *T1 relaxation time* will be shortened.

**Coupled array coils.** *Array coils*, the signals from whose elements are electrically combined prior to processing.

**Coupling**. See *Spin-spin coupling.*

**Coupling constant**. *Spectral lines* are split by *spin-spin coupling* into *multiplets* whose frequencies are separated by an amount depending on the coupling constant, *J*. The magnitude of J is independent of the strength of the applied *magnetic field* and is given in units of *frequency, Hz*.

**CP**. See *Carr-Purcell.*

**CPMG**. See *Carr-Purcell-Meiboom-Gill.*

**Crossed-coil**. *RF coil* pair arranged with their *magnetic fields* at right angles to each other in such a way as to minimize their mutual magnetic interaction.

**Cryogen**. Very low temperature liquified gas (helium or nitrogen) used to maintain superconducting magnets in a superconducting state.

**Cryomagnet**. See *Superconducting magnet.*

**Cryoshielding**. By cooling a metal cylinder surrounding the He-vessel in a *superconducting magnet*, reduced cryogen *boil-off* can be achieved.

**Cryostat**. An apparatus for maintaining a constant low temperature (as by means of liquid helium). Requires vacuum chambers to help with thermal isolation.

**CSI**. See *Chemical shift imaging.*

**CW**. See *Continuous wave.*

# D

**DAC**. See *Digital to analog converter*.

**Data system**. See *Computer*.

**dB**. See *Decibel.*

**dB/dt**. The rate of change of the *magnetic field* (*induction*) with time. Because changing magnetic fields can induce electrical currents, this is one area of potential concern for safety limits.

**DC artifact**. A bright point created in the image caused by a constant offset in signal intensity of all raw data points.

**Decibel (dB)**. A measure of relative power defined as 20 $\log_{10}$ of the relative amplitude of voltage in an electrical circuit or 10 $\log_{10}$ of the relative power, e.g., a factor of 10 change in voltage corresponds to 20 dB and a factor of 100 corresponds to 40 dB.

**Decoupling**. 1) specific irradiation designed to remove the *multiplet* structure in a particular *resonance* due to *spin-spin coupling* with other nuclei; 2) a means of preventing the interaction by mutual *inductive* coupling of two (or more) resonant *RF coils,* e.g., by detuning coils not in use at a particular point in time. Decoupling can take the form of active decoupling where an externally controlled switching circuit is used to detune the non-selected coils or passive decoupling where RF energy from the transmitter pulse is used to switch diodes to detune the appropriate coil.

**$\Delta x$, $\Delta y$, $\Delta z$**. The pixel size (not necessarily equal to the resolution) along the *x*, *y*, or *z* axis.

**Demodulator.** Another term for *detector*, by analogy to broadcast radio receivers.

**Dephasing.** The loss of magnetization in the transverse plane, typically due to the fact that different magnetic dipoles of different nuclei are precessing about the main magnetic field, $B_o$, at slightly different precessional frequencies and therefore lose phase coherence.

**Dephasing gradient**. *Magnetic field gradient* pulse used to create spatial variation of phase of *transverse magnetization*. For example, it may be applied prior to signal detection in the presence of a magnetic field gradient with opposite polarity (or of the same polarity if separated by a *refocusing RF pulse*) so that the resulting *gradient echo* signal will represent a more complete sampling of the *Fourier transform* of the desired image. See also *spoiler gradient pulse.*

**Depth pulses**. Use of multiple *RF pulses* with an inhomogeneous RF field to enable acquiring data from only selected regions within the field. Provides a "one-dimensional" localization along isocontours of the $B_1$ field.

**Detector**. Portion of the *receiver* that demodulates the *RF MR signal* and converts it to a lower *frequency* signal. Most detectors now used are phase sensitive (e.g., *quadrature demodulator/detector*), and will also give phase information about the RF signal.

**Diamagnetic**. A substance that will slightly decrease a *magnetic field* when placed within it (its *magnetization* is oppositely directed to the magnetic field, i.e., with a small negative *magnetic susceptibility*).

**Diffusion**. The process by which molecules or other particles intermingle and migrate due to their random thermal motion. *NMR* provides a sensitive technique for measuring diffusion of some substances.

**Diffusion-weighted imaging (DWI).** Imaging techniques designed to weight the measured MRI signal by the amount of diffusion (random thermal motion) of water molecules in the selected voxels.

**Digital to analog converter (DAC)**. Part of the *interface* that converts digital numbers from the computer into analog (ordinary) voltages or currents.

**Digitization**. Process of conversion of continuous (analog) signals, such as the detected MR signal (voltage), into numbers. This is carried out with an *analog to digital converter*. There are two kinds of discretization involved: the voltage is only measured (*sampled*) at particular discrete times, and only voltages within a particular range and separated by a particular minimum amount can be distinguished. Voltages beyond this range are said to exceed the *dynamic range* of the digitizer.

**Digitization noise**. Noise introduced into *digitized* signals by the finite voltage resolution of the *digitizer*. Also called quantization noise.

**Digitizer**. See *Analog to digital converter.*

**Dipole**. See *Magnetic dipole.*

**Dipole-dipole interaction**. Interaction between a *spin* and its neighbors due to their *magnetic dipole* moments. This is an important mechanism contributing to *relaxation rates*. In solids and viscous liquids this can result in broadening of the *spectral lines*.

**Dipole field**. The field pattern produced by a closely spaced positive and negative electric charge or a north and south magnetic pole. At distances large compared to the dipole length, the field falls off as the third power of the distance away from the charges or poles producing it.

**DWI.** See *Diffusion-weighted imaging*.

**Dynamic range**. Range of signal intensities that may need to be distinguished in an image or spectrum or that can be distinguished by the electronic components. If the signal dynamic range is too great, the need to keep the highest intensities from overloading the *digitizer* may result in the weaker features being lost in the *digitization noise*. This can be dealt with by using an *analog to digital converter* with a larger range of sensitivity or by using techniques to reduce the dynamic range, e.g., *suppressing* the signal from water in order to detect the signal from less abundant compounds.

# E

**Echo**. See *Spin echo.*

**Echo offset**. Adjustment of *RF spin echo* and *gradient echo* to be noncoincident in time, so as to create *phase* differences between the signals from different *spectral lines* (e.g., from fat and water). The magnitude of the resulting phase difference between two lines will be equal to the product of the difference in *frequency* of the lines and the difference in the echo times (*TD*).

**Echo planar imaging (EPI)**. A single-shot *gradient echo* or *spin echo* imaging technique that collects a complete 2D image data set with Cartesian *k-space* coverage from a single excitation. For example, the *FID* is observed while periodically switching the *y-magnetic field gradient* in the presence of a static x-magnetic field gradient. The *Fourier transform* of the resulting *spin echo* train can be used to produce an image of the excited plane.

**Echo spacing**. The time gap between successive echo peaks in a multiple echo imaging pulse sequence. See *Multiple echo imaging*.

**Echo time**. See *TE.*

**Echo train length (ETL)**. The number of echoes combined into a single image or image set in multiple echo imaging sequences or echo-train techniques such as rapid acquisition with relaxation enhancement (RARE), fast-spin echo (FSE), and turbo spin-echo (TSE). In RARE imaging, the ETL typically equals the *acceleration factor*. See *Multiple echo imaging*.

**Eddy current compensation**. Means of reducing the influence of *eddy currents* on pulsed *gradient fields* by employing an electrical *preemphasis* in the gradient amplifiers. Usually multiple time constants have to be used to correct for eddy current effects in various structures of the MR system such as the *cryoshields* and *RF-shields*.

**Eddy currents**. Electric currents induced in a conductor by a changing *magnetic field* or by motion of the conductor through a *magnetic field*. One of the sources of concern about potential hazard to subjects in very high magnetic fields or rapidly varying *gradient* or main magnetic fields. Can be a practical problem in the *cryostat* of *superconducting magnets*. Common means to reduce the influence of eddy currents on gradient fields are *eddy current compensation* and *shielded gradient coils* (active or passive).

**Electron paramagnetic resonance (EPR)**. See *Electron spin resonance.*

**Electron spin resonance (ESR)**. *Magnetic resonance* phenomenon involving unpaired electrons, e.g., in free radicals. The Larmor frequencies are much higher than corresponding *NMR* frequencies in the same static magnetic field.

**Energy level**. In a *magnetic field*, each *spin* can exist in one of a number of distinct states having different energies; this number is determined by the *spin quantum number*.

**EPI.** See *Echo planar imaging*.

**Epoch.** In functional MRI, a portion of fMRI signal measurement during which the stimulus presentation or response task is similar or unchanged.

**EPR.** See *Electron spin resonance.*

**ESR**. See *Electron spin resonance.*

**Ernst angle**. The RF excitation angle cos $\theta_E$ at which the signal is a maximum for a short-TR steady-state incoherent sequence. The Ernst angle is found from the relation $\cos \theta_E = \exp(-TR/T1)$.

**ETL**. See *Echo train length.*

**Even echo rephasing**. A rephasing which occurs when constant velocity spins return to the same starting phase they had directly after the initial exciting RF pulse, as a result of the application of an even number of gradient pulses. This may also result from the application of multiple gradient echo pulses following the RF pulse.

**Excitation**. Putting energy into the *spin* system; if a net *transverse magnetization* is produced, an *MR signal* can be observed.

**Exponential weighting**. In spectroscopy, multiplication of the time-dependent signal data by an exponential function, exp(t/TC), where t is time and TC is a parameter called the time constant. The time constant can be chosen to either improve the *signal-to-noise* ratio (with a negative TC) or decrease the effective *spectral line* width (with a positive TC) in the resulting *spectrum*. The use of a negative TC to improve *SNR* is equivalent to *line* broadening by convolving the spectrum with a *Lorentzian* function of corresponding reciprocal width.

# F

**f**. See *Frequency*.

**Faraday shield**. Electrical conductor interposed between *transmitter* and/or *receiver coil* and patient to block out electric fields.

**Fast Fourier transform (FFT)**.  An efficient computational method of performing a *Fourier transform*.

**Fat Suppression.**  MRI pulse sequence techniques in which the signal from hydrogen-containing lipids (mostly $CH_2$) is reduced compared to the signal from water-containing tissues.

**Ferromagnetic**.  A substance, such as iron, that has a large positive *magnetic susceptibility*.

**FFT**.  See *Fast Fourier transform*.

**FID**.  See *Free induction decay.*

**Field echo**.  See *Gradient echo.*

**Field gradient**.  See *Magnetic field gradient.*

**Field lock**.  A feedback control used to maintain the static *magnetic field* at a constant strength, usually by monitoring the *resonance frequency* of a reference sample or line in the *spectrum*.

**Field of view (FOV).**  The rectangular region superimposed over the human body over which MRI data are acquired.  Its dimensions are specified in length in each in-plane direction and are controlled by the application of frequency-encode and phase-encode gradients.

**Filling factor**.  A measure of the geometrical relationship of the *RF coil* and the object being studied. It affects the efficiency of *exciting* the object and detecting *MR signals*, thereby affecting the *signal-to-noise ratio* and, ultimately, image quality. Achieving a high filling factor requires fitting the coil closely to the object, thus potentially decreasing patient comfort.

**Filter**.  Filtering is any process which alters the relative frequency content. This can be done with an analog (conventional electrical) filter, e.g., to remove higher frequency components so as to avoid *aliasing* in digitizing. Filtering can be carried out numerically on the digitized data.

**Filtered back projection**. Mathematical technique used in *projection-reconstruction imaging* to create images from a set of multiple *projection profiles*. The projection profiles are back projected to produce a two (or three) dimensional image. The projection profiles are processed by convolving them with a suitable mathematical function (filtered) prior to back projecting them, in order to improve the image. Widely used in conventional computed tomography (CT).

**Flip angle**.  Amount of rotation of the *macroscopic magnetization vector* produced by an *RF pulse*, with respect to the direction of the static *magnetic field*.

**Flow compensation**.  Means of reducing *flow effects*, e.g., *gradient moment nulling*.

**Flow effects**. Motion of material being imaged, particularly flowing blood, can result in many possible effects in the images, including increase in the signal ("*flow-related enhancement*"), decrease in the signal or displacement of the signal (image misregistration). These effects can be understood as being caused by *time-of-flight* effects (washout or washin due to motion of nuclei between two consecutive spatially selective RF excitations, repeated in times on the order of or shorter than the relaxation times of blood) or *phase* shifts that can be acquired by excited spins moving along *magnetic field gradients*. The inconsistency of the signal resulting from pulsatile flow can lead to *artifacts* in the image; these can be reduced by *synchronization* of the imaging sequence with the heart cycle ("cardiac *gating*"), suppression of the blood signal with *saturation pulses*, or reduction of phase shifts with *gradient moment nulling*. The flow effects can also be exploited for MR *angiography* or flow measurements.

**Flow-related enhancement**. The increase in intensity that may be seen for flowing blood or other liquids with some *MR imaging* techniques, due to the washout of *saturated* spins from the imaging region.

**Flow void**. The occurrence of low signal in regions of flow. For a spin echo sequence, this is caused in part by a lack of refocussing of blood which is excited by the 90° pulse but not by the 180° pulse. For a gradient echo sequence, this is caused by the dephasing of blood signal.

**fMRI.** See *Functional magnetic resonance imaging***.**

**Fourier transform (FT)**. A mathematical procedure to separate out the *frequency* components of a signal from its amplitudes as a function of time, or vice versa. The Fourier transform is used to generate the *spectrum* from the *FID* or *spin echo* in *pulse MR* techniques and is essential to most *MR imaging* techniques. The Fourier transform can be generalized to multiple dimensions, e.g., to relate an image to its corresponding *k-space* representation, or to include *chemical shift* information in some *chemical shift imaging* techniques.

**Fourier transform imaging**. *MR imaging* techniques in which at least one dimension is *phase-encoded* by applying variable *gradient pulses* along that dimension before "reading out" the MR signal with a *magnetic field gradient* perpendicular to the variable gradient. The *Fourier transform* is then used to reconstruct an image from the set of encoded MR signals. An imaging technique of this type is *spin warp imaging*.

**FOV**. See *Field of view***.**

**Free induction decay (FID)**. If *transverse magnetization* of the spins is produced, e.g., by a 90° pulse, a transient *MR signal* will result that will decay toward zero with a characteristic time constant *T2* (or *T2**); this decaying signal is the FID. In practice, the first part of the FID is not observable due to residual effects of the powerful exciting *RF pulse* on the electronics of the receiver, the *receiver dead time*.

**Frequency (f)**. The number of repetitions of a periodic process per unit time. The old unit, cycles per second (cps), has been replaced by the SI unit, *hertz*, abbreviated *Hz*. It is related to *angular frequency*, ω, by $f = \omega/2\pi$.

**Frequency encoding**. Encoding the distribution of sources of *MR* signals along a direction by detecting the signal in the presence of a *magnetic field gradient* along that direction so that there is a corresponding gradient of *resonance frequencies* along that direction. In the absence of other position encoding, the Fourier transform of the resulting signal is a one-dimensional *projection profile* of the object.

**Frequency offset**. The difference between given signal frequency and a reference frequency.

**Frequency selective RF pulse**. An RF pulse containing energy only within a specified frequency range. Usually used for slice excitation or for selective saturation pulses.

**Fringe field**. See *Magnetic fringe field.*

**FT**. See *Fourier transform.*

**Full-width at half-maximum (FWHM)**. A commonly used measure of the width at half the maximum value of peaked functions such as *spectral lines* or *slice profiles*. For a spectral line, this will be proportional to 1/*T2*.

**Functional magnetic resonance imaging (fMRI).** The use of MRI to study function in addition to anatomy. In the brain, fMRI measures changes in cerebral blood flow and cerebral blood oxygenation as correlates of neuronal activity (*See*, for example, *Blood oxygen level dependent effect*). fMRI is also used to study function of the heart and other organs.

**FWHM**. See *Full-width at half-maximum.*

# G

**G**. See *Gauss.*

**$G_x$, $G_y$, $G_z$**. Conventional symbols for *magnetic field gradient*. Used with subscripts to denote spatial direction component of gradient, i.e., direction along which the field changes.

**Gadolinium**. Lanthanide element that is paramagnetic in its trivalent state. It has been used as the active component of most *contrast agents* in MR imaging because of its effect of strongly decreasing the *T1 relaxation times* of the tissues to which it has access. Although toxic by itself, it can be given safely in a chelated form such as Gd-DTPA, which still retains much of its strong effect on relaxation times.

**Gating**. *Synchronization* of imaging with a phase of the cardiac or respiratory cycles. A variety of means for detecting these cycles can be used, such as the ECG, peripheral pulse, chest motion, etc. The synchronization can be *prospective* or *retrospective*.

**Gauss (G)**. A unit of magnetic flux density in the older (CGS) system. The Earth's magnetic field is approximately one half gauss to one gauss, de-pending on location. The currently preferred (SI) unit is the *tesla* (T) (1 T = 10,000 G).

**Gaussian line shape**. *A line shape* characterized by a bell-shaped form; proportional to exp $(-(f - f_0)^2/\Delta f^2)$ where $\Delta f$ is a measure of the line width.

**Gaussian noise**. Noise distributed in a normal (Gaussian) pattern. In such a distribution, approximately 65% of all points fall within one standard deviation (s) of the mean.

**Gibbs phenomenon**. Artifactual ripples that occur near a discontinuity when reconstructing a mathematical function from only a finite portion of its *Fourier transform*. In MR imaging, it can be seen as linear artifacts parallel to sharp edges in the object, particularly with the use of *zero filling*. See also *Truncation artifact*.

**Gigahertz (GHz)**. Unit of *frequency*; equal to one thousand *MHz*.

**Golay coil**. Term commonly used for a particular kind of *gradient coil*, commonly used to create *magnetic field gradients* perpendicular to the main magnetic field.

**Gradient**. The amount and direction of the rate of change in space of some quantity, such as *magnetic field strength*. Also commonly used to refer to *magnetic field gradient.*

**Gradient and spin-echo imaging (GRASE).** A hybrid MR pulse sequence in which both gradient-echo and spin-echo techniques are combined to acquire multiple lines in k-space during measurement following a single spin-echo excitation.

**Gradient coils**. Current carrying *coils* designed to produce a desired *magnetic field gradient* (so that the magnetic field will be stronger in some locations than others). Proper design of the size and configuration of the coils is necessary to produce a controlled and uniform gradient.

**Gradient-echo**. A signal echo produced by reversing the direction of a *magnetic field gradient* or by applying balanced pulses of magnetic field gradient before and after a refocusing *RF pulse* so as to cancel out the position-dependent *phase* shifts that have accumulated due to the gradient. In the latter case, the gradient echo is generally adjusted to be coincident with the RF spin echo. When the RF and gradient echoes are not coincident, the time of the gradient echo is denoted *TE* and the difference in time between the echoes is denoted *TD,* while *TER* refers to the time of the RF spin echo.

**Gradient-echo pulse sequence**. A pulse sequence that relies on gradient reversal to rephrase the transverse magnetization. Gradient-echo pulse sequences permit small flip-angle excitations, which preserve most of the longitudinal magnetization and therefore reduce or eliminate the time required for recovery of longitudinal magnetization before repeating the pulse sequence. Gradient echo pulse sequences have gained common use in 2DFT (planar) and 3DFT (volume) imaging, flow imaging, magnetic susceptibility imaging, and BOLD imaging.

**Gradient magnetic field**. See *Magnetic field gradient.*

**Gradient moment nulling**. Adjustment to zero at the time *TE* of the net moments of the amplitude of the waveform of the *magnetic field gradients* with time (e.g., zeroth moment is the area under the curve, first moment is the "center of gravity," etc). The aim is to minimize the *phase* shifts acquired by the *transverse magnetization* of excited nuclei moving along the gradients (including the effect of *refocusing RF pulses*), particularly for the reduction of image artifacts due to motion.

**Gradient pulse**. Briefly applied *magnetic field gradient*.

**Gradient recalled echo**. See *Gradient echo.*

**Gyromagnetic ratio (γ)**. The ratio of the *magnetic moment* to the *angular momentum* of a particle. This is a constant for a given nucleus.

# H

**$H_o$**. Conventional symbol historically used for the constant *magnetic field* in an *MR system*; it is physically more correct to use $B_o$. A magnet provides a field strength, H; however, at a point in an object, the *spins* experience the *magnetic induction*, B. See section on “Basic Quantities in Electricity and Magnetism” in the back of the Glossary for further discussion.

**$H_1$**. Conventional symbol historically used for the radiofrequency *magnetic field* in an *MR system*; it is physically more correct to use $B_1$. It is useful to consider it as composed of two oppositely rotating *vectors*. At the *Larmor frequency*, the vector rotating in the same direction as the *precessing spins* will interact strongly with the spins. See section on “Basic Quantities in Electricity and Magnetism” in the back of the Glossary for further discussion.

**Hahn echo**. Production of *spin echo* by repeated *RF pulses*. First observed using equal (90°) RF pulses, now commonly used to describe refocusing of transverse magnetization by a 180° RF pulse.

**Half Fourier**. See *Partial Fourier.*

**Hardware**. Electrical and mechanical components of the *spectrometer* or *computer*.

**Helmholtz coil.** Pair of current carrying *coils* used to create uniform *magnetic field* in the center of the space between them. For circular coils, their separation equals their radius.

Hemodynamic response. Changes in blood flow, blood volume, and blood oxygenation as a result of local neural activity.

**Hertz (Hz)**. The standard (*SI*) unit of *frequency*; equal to the old unit cycles per second.

**Homogeneity**. Uniformity. In *MR*, the homogeneity of the static *magnetic field* is an important criterion of the quality of the magnet. Homogeneity requirements for *MR imaging* are generally lower than the homogeneity requirements for NMR spectroscopy, but for most imaging techniques must be maintained over a large region.

**Homospoil**. Use of a *magnetic field gradient* to effectively eliminate residual *transverse magnetization* by producing a strong position dependence of *phase* within a *resolution element*. Also called *Spoiler pulse*.

**Hybrid magnet**. Magnet system employing both current-carrying coils and permanently magnetized material to generate the *magnetic field*.

**Hz**. See *Hertz.*

# I

**I**. See *Spin quantum number.*

**Isotropic Imaging.** Imaging in which voxel dimensions are equal in x, y, and z directions.

**Image acquisition time**. Time required to carry out an *MR imaging* procedure comprising only the data acquisition time. The total image acquisition time will be equal to the product of the repetition time, *TR*, the number of signals averaged, *NSA*, and the number of different signals (encoded for position) to be acquired for use in image reconstruction. The additional image reconstruction time will also be important to determine how quickly the image can be viewed. In comparing *sequential plane imaging* and *volume imaging* techniques, the equivalent image acquisition time per slice must be considered as well as the actual image acquisition time.

**Imaginary signal**. Out-of-phase component of the signal from a *quadrature detector*.

**Impedance matching**. Adjusting the electrical impedances of two circuits that are to be joined at an interface so that they are equal, e.g., with a *matching network*.

**Incoherent spins**. A state of a set of spins in which the ensemble of spins in a voxel are uniformly distributed with phases between 0 and 2p reducing the transverse magnetization in a voxel to essentially zero.

**Inductance**. Measure of the magnetic coupling between two current-carrying loops (mutual) reflecting their spatial relationship or of a loop (such as a *coil*) with itself (self). One of the principal determinants of the *resonance frequency* of an RF circuit.

**Induction (B).** See *Magnetic induction*.

**Inhomogeneity**. Degree of lack of *homogeneity*, for example the fractional deviation of the local *magnetic field* from the average value of the field.

**In-phase image**. An image in which the signals from two spectral components (such as fat and water) add constructively in a voxel.

**Interleaved image acquisition**. The joint collection of data for two or more separate images such that a subset of k-space samples for the second image is acquired immediately after that for the first image. This method avoids misregistration between the two images and allows for accurate subtraction of the two images.

**Interleaved k-space coverage**. The sequential collection of raw data from multiple excitations such that each excitation samples multiple lines or curvilinear paths in k-space.

**Interpulse times (t)**. Times between successive *RF pulses* used in *pulse sequences*. Particularly important are the inversion time *(TI)* in *inversion recovery*, and the time between *90° pulse* and the subsequent *180° pulse* to produce a *spin echo*, which will be approximately one half the *spin echo* time *(TE)*. The time between repetitions of pulse sequences is the *repetition time (TR)*.

**Inverse Fourier transform**. Form of the *Fourier transform* that reverses the process, e.g., if the Fourier transform is used to analyze a function of time into its equivalent *frequency* components, the inverse Fourier transform will synthesize that function of time from these frequency components.

**Inversion**. A nonequilibrium state in which the *macroscopic magnetization vector* is oriented opposite to the *magnetic field*; usually produced by *adiabatic fast passage* or *180° RF pulses*.

**Inversion-recovery (IR)**. Pulsed MR imaging sequence wherein the nuclear magnetization is inverted at a time on the order of T1 before the regular imaging pulse-gradient sequences. The resulting partial *relaxation* of the spins in the different structures being imaged can be used to produce an image that depends strongly on T1. This may bring out differences in the appearance of structures with different T1 relaxation times. Note that this does *not* directly produce an image of T1. T1 in a given region can be calculated from the change in the *NMR signal* from the region due to the inversion pulse compared to the signal with no inversion pulse or an inversion pulse with a different inversion time *(TI)*.

**Inversion-recovery-spin-echo (IRSE)**. Form of *inversion-recovery* imaging in which the signal is detected as a *spin echo*. For *TE* short compared to the *T2 relaxation time*, there will be only a small effect of T2 differences on image intensities; for longer TEs, the effect of T2 may be significant.

**Inversion time**. See *TI.*

**Inversion transfer**. See *Saturation transfer.*

**IR**. See *Inversion recovery.*

**IRSE**. See *Inversion-recovery-spin-echo.*

**Isocenter, magnetic.** The position in the magnet which is centered in the x, y, and z direction. At this location the static magnetic field is typically highest in uniformity.

**Isochromat**. A microscopic group of spins which resonate at the same frequency. For example, a set of spins moving together in the direction of a magnetic field gradient yet jointly experiencing the same field at any given time.

**Isotopes**. Atoms with varying numbers of neutrons but with the same number of protons. For example, $^{1}H$, $^{2}H$, and $^{3}H$ are the three isotopes of hydrogen, otherwise known as proton, deuterium, and tritium. Various isotopes have different *nuclear magnetic moments* and, hence, have quite different *resonant frequencies*. Many isotopes have no magnetic moment and, hence, are therefore not observable by *NMR*.

**Isotropic motion**. Motion which is uniform in all directions. This is generally used in reference to molecular *diffusion* or rotation which gives rise to relaxation of the spin system through *dipole-dipole interactions*.

**Isotropic voxel**. A voxel with equal physical dimensions in x, y, and z directions.

# J

**J**. Commonly used to denote *coupling constant*, the frequency difference produced by *spin-spin coupling*.

**J-coupling**. See *Spin-spin coupling.*

**J-modulation.** Changes in the relative *phase* of the component lines of a *multiplet* (see *Spin-spin coupling*) caused by differential phase accumulations, dependent on the particular acquisition parameters employed. For example, in *multiple spin echo* sequences the resulting modulation of the net intensity of the multiplet can affect the apparent *T2s* in a manner dependent on the choice of interpulse delays employed to observe the echo.

# K

**k**. Boltzmann's constant; appears in *Boltzmann distribution*.

**Keyhole imaging.** A form of dynamic imaging that increases temporal resolution without degrading spatial resolution by updating only a portion of k-space rapidly and frequently. The center of k-space which is updated more rapidly forms the "keyhole". The remainder of k-space is updated less frequently to provide adequate spatial resolution.

**kHz**. See *Kilohertz.*

**Kilohertz (kHz)**. Unit of *frequency*; equal to one thousand *hertz*.

**k-space**. Mathematical space in which the *Fourier transform* of the image is represented. The data acquired for MR image reconstruction generally correspond to samples of k-space, that is, they represent values of the Fourier transform of the image at a particular set of locations in k-space. See also *Spatial frequency*.

**k-space filling.** The location and order of obtaining data in two-dimensional spatial frequency space (k-space), the Fourier transform of which comprises the MR image. For example, conventional MR pulse sequences such as spin-echo and gradient-echo imaging fill a single line of k-space with each data measurement. A different phase encoding step is used to fill out another parallel line of k-space. The full set of measurements completes a Cartesian grid of points in k-space. Other options for k-space filling include radial filling (back-projection imaging) or spiral filling (spiral imaging).

**k-space trajectory**. The path traced in the *spatial-frequency* domain during data collection as determined by the applied gradients.

# L

**Larmor equation**. States that the *frequency* of precession of the nuclear *magnetic moment* is proportional to the *magnetic field*.

$\omega_o = -\gamma B_o$ (radians per second)

or

$f_o = -\gamma B_o/2\pi$ (hertz)

where $w_o$ or $f_o$ is the frequency, $\gamma$ is the *gyromagnetic ratio*, and $B_o$ is the magnetic induction field. The negative sign indicates the direction of the rotation.

**Larmor frequency ($\omega_o$ or $f_o$)**. The *frequency* at which *magnetic resonance* can be excited; given by the *Larmor equation*. By varying the *magnetic field* across the body with a *magnetic field gradient*, the corresponding variation of the Larmor frequency can be used to encode position. For protons (hydrogen nuclei), the Larmor frequency is 42.58 MHz/tesla.

**Lattice**. By analogy to *NMR* in solids, the magnetic and thermal environment with which nuclei exchange energy in *longitudinal relaxation*.

**Line imaging**. See *Sequential line imaging.*

**Line scanning**. See *Sequential line imaging.*

**Line shape**. Distribution of the relative strength of *resonance* as a function of *frequency* which establishes a particular *spectral line*. Common line shapes are *Lorentzian* and *Gaussian*.

**Line, spectral**. See *Spectral line.*

**Line spread function (LSF).** A hypothetical point-like or delta-function object in one dimension will generally have an extended (blurred) image resulting from the imaging process; this is the line spread function characterizing the imaging process. Knowledge of the LSF permits the prediction of how the object will be imaged in that one direction, assuming *linearity* of the imaging process. The Fourier transform of the line spread function is the modulation transfer function (MTF).

**Line width**. Spread in *frequency* of a resonance line in a *MR spectrum*. A common measure of the line width is *full-width at half-maximum (FWHM).*

**Linearity**. 1) fidelity of response, e.g., of *magnetic field gradients* or *RF* system, to input. The output of a linear system is directly proportional to its input. 2) spatial uniformity of the magnetic field gradient over the imaging volume. Because of *eddy current* effects static and dynamic linearity have to be distinguished. Both together with the magnet homogeneity determine the geometrical correctness of the images.

**Linearly polarized coil (LP coil)**. A coil designed to excite or detect spins using one RF transmit and/or receive channel. The magnetic field has predominately a single direction.

**Liquifier**. System for reliquification of cryogenic gases; if closely matched with a *superconducting magnet*, zero net *cryogen boil-off* can be achieved.

**LMR**. See *Localized magnetic resonance.*

**Loading**. See *Coil loading.*

**Localization techniques**. Means of selecting a restricted region from which the signal is received. These can include the use of *surface coils*, with or without *magnetic field gradients*. Generally used to produce a *spectrum* from the desired region.

**Localized magnetic resonance (LMR)**. A particular technique for obtaining *MR spectra*, for example, of phosphorus, from a limited region by creating a *sensitive volume* with *inhomogeneous* applied *gradient magnetic fields*, which may be enhanced with the use of *surface coils*.

**Lock**. See *Field lock.*

**Longitudinal magnetization ($M_z$)**. Component of the *macroscopic magnetization vector* along the static *magnetic field*. Following excitation by *RF pulse,* $M_z$ will approach its equilibrium value $M_o$, with a characteristic time constant *T1*.

**Longitudinal relaxation**. Return of *longitudinal magnetization* to its equilibrium value after excitation; requires exchange of energy between the *nuclear spins* and the *lattice*.

**Longitudinal relaxation time**. See *T1*.

**Lorentzian line**. Usual shape of the lines in an NMR *spectrum*, characterized by a central peak with long tails; proportional to $1/[(1/T2)^2 + (f - f_o)^2]$, where f is *frequency* and $f_o$ is the frequency of the peak (i.e., central resonance frequency). A Lorentzian function is the *Fourier transform* of a decaying *exponential*.

**LSF.** See *Line spread function*.

# M

**M**. Conventional symbol for *macroscopic magnetization vector*.

**$M_{xy}$**. See *Transverse magnetization.*

**$M_z$**. See *Longitudinal magnetization.*

**$M_o$**. Equilibrium value of the magnetization; directed along the direction of the static magnetic field, $\mathbf{B_o}$. Proportional to spin density, N.

**Macroscopic magnetic moment.** See *Macroscopic magnetization vector.*

**Macroscopic magnetization vector**. Net *magnetic moment* per unit volume (a vector quantity) of a sample in a given region, considered as the integrated effect of all the individual microscopic nuclear magnetic moments.

**Magnet stability**. Temporal stability of the *magnetic field*. Factors to be considered are field decay of *superconducting magnets* in persistent mode, aging of *permanent* magnet material, temperature dependence of permanent magnet material, and temporal stability of magnet power supplies.

**Magnetic dipole**. North and south magnetic poles separated by a finite distance. An electric current loop, including the effective current of a spinning *nucleon* or nucleus, can create an equivalent magnetic dipole.

**Magnetic field (H)**. The region surrounding a magnet (or current carrying conductor) is endowed with certain properties. One is that a small magnet in such a region experiences a *torque* that tends to align it in a given direction. Magnetic field is a *vector* quantity; the direction of the field is defined as the direction that the north pole of the small magnet points when in equilibrium. A magnetic field produces a magnetizing force on a body within it. Although the dangers of large magnetic fields are largely hypothetical, this is an area of potential concern for safety limits.

Formally, the forces experienced by moving charged particles, current carrying wires, and small magnets in the vicinity of magnet are due to *magnetic induction* (B), which includes the effect of *magnetization*, while the magnetic field (H) is defined so as not to include magnetization. However, both B and H are often loosely used to denote magnetic fields. See section on “Basic Quantities in Electricity and Magnetism” in the back of the Glossary for further discussion.

**Magnetic field gradient**. A *magnetic field* which changes in strength in a certain given direction. Such fields are used in *MR imaging* with *selective excitation* to select a region for imaging and also to encode the location of *MR signals* received from the object being imaged. Measured (e.g.) in *teslas* per meter.

**Magnetic forces**. Forces resulting from the interaction of *magnetic fields*. Pulsed *magnetic field gradients* can interact with the main magnetic field to produce *acoustic noise* through the gradient *coil*. Magnetic fields attract *ferromagnetic* objects with forces which can be lethal if one is hit by an unrestrained object in flight. One could also be trapped between the magnet and a large unrestrained ferromagnetic object or the object could damage the MR system. Access control and personnel awareness are the best prevention of such accidents. The attraction mechanism for ferromagnetic objects is that the *magnetic field* magnetizes the iron. This induced magnetization reacts with the *gradient* of the magnetic field to produce an attraction toward the strongest area of the field. The details of this interaction are very dependent on the shape and composition of the attracted object. There is a very rapid increase of force as one approaches a magnet. There is also a *torque* or twisting force on objects, e.g., a long cylinder (such as a pen or an intracranial aneurysm clip) will tend to align along the magnet's field lines. The torque increases with field strength while the attraction increases with field gradient. Depending on the magnetic saturation of the object, attraction is roughly proportional to object mass. Motion of conducting objects in magnetic fields can induce *eddy currents* that can have the effect of opposing the motion.

**Magnetic fringe field**. The region surrounding a magnet and exhibiting a *magnetic field* strength which is significantly higher than the earth's magnetic field (typically 0.05-0.1 mT, depending on geographical location). Due to the physical properties of magnetic fields, the magnetic flux which penetrates the useful volume of the magnet will return through the surroundings of the magnet to form closed field lines. Depending on the magnet construction, the returning flux will penetrate large open spaces (unshielded magnets) or will be confined largely to iron yokes or through secondary coils (*shielded magnets*).

**Magnetic induction (B)**. Also called magnetic flux density. The net magnetic effect from an externally applied *magnetic field* and the resulting *magnetization*. B is proportional to H ($B = \mu H$), with the *SI* unit being the *tesla*. See section on "Basic Quantities in Electricity and Magnetism" in the back of the Glossary for further discussion.

**Magnetic moment.** A measure of the net magnetic properties of an object or particle. A nucleus with an intrinsic spin will have an associated *magnetic dipole* moment, so that it will interact with a *magnetic field* (as if it were a tiny bar magnet).

**Magnetic resonance (MR)**. *Resonance* phenomenon resulting in the absorption and/or emission of electromagnetic energy by nuclei or electrons in a static *magnetic field*, after excitation by a suitable *RF* magnetic field. The peak *resonance frequency* is proportional to the magnetic field, and is given by the *Larmor equation*. Only unpaired electrons or nuclei with a non-zero *spin* exhibit magnetic resonance.

**Magnetic resonance angiography (MRA)**. *Angiography* using MRI.

**Magnetic resonance imaging (MRI)**. Use of magnetic resonance to create images of objects such as the body. Currently, this primarily involves imaging the distribution of mobile hydrogen nuclei (protons) in the body. The image brightness depends jointly on the spin density (N(H)) and the *relaxation times* (T1 and T2), with their relative importance depending on the particular imaging technique and choice of *interpulse times*. Image brightness is also affected by any motion such as blood flow, respiration, etc.

**Magnetic resonance spectroscopy (MRS)**. Use of *magnetic resonance* to study the MR *spectrum* of a sample or a tissue region. In addition to the effects of factors such as *relaxation times* that can affect the MR signal as seen in magnetic resonance imaging, effects such as *J-modulation* or the transfer of *magnetization* after selective excitation of particular *spectral lines* can affect the relative strengths of spectral lines. The *frequencies* of certain lines may also be affected by factors such as the local pH.

**Magnetic shielding**. Means to confine the region of strong magnetic field surrounding a magnet; most commonly the use of material with high *permeability* (*passive shielding*) or by employing secondary counteracting *coils* outside of the primary coils (*active shielding*). The high permeability material can be employed in the form of a *yoke* immediately surrounding the magnet (*self-shielding*) or installed in the walls of a room as full or partial *room-shielding*. Unlike shielding ionizing radiation, for example, magnetic shielding can only be accomplished by forcing the unavoidable magnetic return flux through more confined areas or structures, not by absorbing it.

**Magnetic susceptibility ($\chi$)**. Measure of the ability of a substance to become magnetized.

**Magnetization**. (see also *Macroscopic magnetization vector*). The magnetic polarization of a material produced by a magnetic field (magnetic moment per unit volume).

**Magnetization transfer**. The change in magnetization within a multicomponent spin system when one of the component peaks is selectively perturbed. This is observed as a change in relative signal intensities. One of the most common forms of perturbation in imaging is selective *saturation*. For example, this phenomenon can be exploited as part of an imaging sequence to produce image contrast based on differential amounts of magnetization transfer, *magnetization transfer contrast (MTC).*

**Magnetization transfer contrast (MTC)**. Production of change in relative signal intensities by *magnetization transfer*. For example, *saturation* of broad *spectral lines* may produce decreases in intensity of lines not directly saturated, through exchange of magnetization between the corresponding states; more closely coupled states will show a greater resulting intensity change.

**Magnetogyric ratio**. See *Gyromagnetic ratio.*

**Magnitude calculation**. The result of taking the square root of the sum of the squares of the *real* and *imaginary* parts of an *MR* signal.

**Matching**. See *Impedance matching*.

**Matching network**. An arrangement of reactive elements (inductors and capacitors) used to transform an input impedance of a given value to an output impedance of a second value. Such circuits are used in interfacing high impedance RF coils to low impedance (usually 50 ohms) transmission lines that feed RF energy to the coil or send the MR signal to an MR preamplifier.

**Matrix size**. The number of data points collected in one, two or all three directions. Normally used for the 2D in-plane sampling. The display matrix may be different from the acquisition matrix, although resolution is determined by the latter. (See also Nx, Ny, Nz.)

**Maximum intensity projection (MIP)**. A projection image which is obtained from a 3D data set by selecting the maximum intensity along lines or rays that cut through the 3D image volume.

**Maxwell coil**. A particular kind of *gradient coil*, commonly used to create *magnetic field gradients* along the direction of the main magnetic field.

**Megahertz (MHz)**. Unit of *frequency*, equal to one million *hertz*.

**Meiboom-Gill sequence**. See *Carr-Purcell-Meiboom-Gill sequence.*

**MHz**. See *Megahertz.*

**Moment**. See *Magnetic moment.*

**MPR (multiplanar reconstruction)**. The reformatting of a 3D data set into 2D slices of arbitrary thickness at any angle.

**MR**. See *Magnetic resonance.*

**MR Signal**. See *Raw Data.*

**MRA**. See *Magnetic resonance angiography.*

**MRI**. See *Magnetic resonance imaging.*

**MRS**. See *Magnetic resonance spectroscopy.*

**MTC**. See *Magnetization transfer contrast.*

**Multiple coil array**. A set of decoupled RF coils, usually in receive mode, arranged to cover the whole region of interest. It has both the spatial coverage of a large region-of-interest coil and the high SNR of a surface coil.

**Multiple echo imaging**. *Spin echo imaging* or echo-train pulse sequence techniques such as rapid acquisition with relaxation enhancement (RARE) techniques (fast spin-echo (FSE) or turbo-spin echo (TSE)) in which more than one echo is acquired per excitation pulse. *Carr-Purcell (CP) sequences* and *Carr-Purcell-Meiboom-Gill (CPMG) sequences* are examples of multiple-echo imaging techniques in which distinct images are constructed from signal echoes acquired at a different TE values, yielding different T2 weighting to each image set. Echo-train or RARE techniques speed image acquisition by applying a different phase-encoding to each echo, speeding image acquisition, but blending echoes with different T2 weightings into a single image set.

**Multiple line-scan imaging (MLSI)**. Variations of *sequential line imaging* techniques that can be used if *selective excitation* methods that do not affect adjacent lines are employed. Adjacent lines are imaged while waiting for *relaxation* of the first line toward equilibrium, which may result in decreased *image acquisition time*. A different type of MLSI uses simultaneous excitation of two or more lines with different phase encoding followed by suitable decoding.

**Multiple quantum coherence**. *Excitation* by an *RF pulse* can be considered as creating a transition (or "coherence") between different *energy levels*. Formally, transitions are only allowed between states of the *spin* system differing in quantum number by one unit ("single-quantum coherence"), but multiple RF pulses can act in cascade and produce multiple-quantum coherence.Only single quantum coherence produces a directly observable signal, however, requiring indirect observation of multiple-quantum frequencies.

**Multiple sensitive point.** *Sequential line imaging* technique utilizing two orthogonal oscillating *magnetic field gradients*, an *SFP pulse sequence*, and signal averaging to isolate the *MR spectrometer* sensitivity to a desired line in the body.

**Multiple slice imaging**. Variation of *sequential plane imaging* techniques that can be used with *selective excitation* techniques that do not affect adjacent slices. Adjacent slices are imaged while waiting for *relaxation* of the first slice toward equilibrium, resulting in decreased *image acquisition time* for the set of slices.

**Multiple spin echo**. A *pulse sequence* leading to the production of multiple *spin echoes* after an initial *excitation* pulse. See *Carr-Purcell (CP) sequences* and *Carr-Purcell-Meiboom-Gill (CPMG) sequences, for example.*

**Multiplet**. A pattern of multiple *resonances* (*spectral lines*) observed when the initially single *Larmor frequency* of a given nucleus in a spin system is split by interactions with neighboring spins through the scalar or *spin-spin* interaction. The magnitude of this interaction is independent of the applied magnetic field and is referred to as $J$, the spin-spin coupling constant. The specific pattern produced depends on the number of coupled nuclei and their *spin quantum numbers*.

**Multiply tuned coil**. *RF coil* designed to operate at more than one *resonance frequency*, so that *MR* of more than one kind of nucleus can be observed with the same coil.

# N

**N(H)**. See *Spin density.*

**NEX**. See *NSA.*

**NMR**. See *Nuclear magnetic resonance.*

**NMR imaging**. (See also *Zeugmatography* and *magnetic resonance imaging*). Creation of images of objects such as the body by use of the nuclear magnetic resonance phenomenon. The immediate practical application involves imaging the distribution of hydrogen nuclei (protons) in the body. The image brightness in a given region is usually dependent jointly on the *spin density* and the *relaxation times*, with their relative importance determined by the particular imaging technique employed. Image brightness is also affected by motion such as blood flow.

**NMR signal.** Electromagnetic signal in the *radiofrequency* range produced by the *precession* of the *transverse magnetization* of the *spins*. The rotation of the transverse magnetization induces a voltage in a *coil*, which is amplified and demodulated by the *receiver*; the signal may refer only to this induced voltage.

**NOE**. See *Nuclear Overhauser effect.*

**Noise**. That component of the reconstructed image (or spectrum) due to random and unpredictable processes as opposed to the *signal* within the image itself which is due to predictable processes. Not to be confused with artifacts which are non-random errors in the image. It is commonly characterized by the standard deviation of signal intensity in the image of a uniform object (phantom) in the absence of *artifacts*. The measured noise may depend on the particular phantom used due to variable effects on the Q of the *receiver coil*.

**Noise figure**. A measure of the noise performance of an amplifier or chain of amplifiers such as an MR *receiver*. In MR systems the *preamplifier* should have a very low noise figure to prevent significant degradation of the *signal-to-noise ratio* of the MR signal. Noise figure is a ratio in *dB*s, and is given by: 20 log $[V_o/(V_i G)]$ where $V_i$ is the input thermal noise voltage, $V_o$ is the amplifier output noise level and G is the voltage gain of the amplifier (when the input and output impedances of the amplifier are equal).

**NSA**. Number of signals averaged together to determine each distinct position-encoded signal to be used in image reconstruction.

**Nuclear magnetic resonance (NMR)**. The absorption or emission of electromagnetic energy by nuclei in a static *magnetic field*, after *excitation* by a suitable *RF* magnetic field. The peak *resonance frequency* is proportional to the magnetic field, and is given by the *Larmor equation*. Only nuclei with a non-zero *spin* exhibit NMR.

**Nuclear Overhauser effect (NOE)**. A change in the steady state magnetization of a particular nucleus due to irradiation of a neighboring nucleus with which it is coupled by means of a *spin-spin coupling* interaction. This interaction must be the primary relaxation mechanism of these nuclei. Such an effect can occur during *decoupling* and must be taken into account for accurate intensity determinations during such procedures.

**Nuclear spin** (see also *Spin*). An intrinsic property of certain nuclei that gives them an associated characteristic *angular momentum* and *magnetic moment*.

**Nuclear spin quantum number (I)**. See *Spin quantum number*.

**Nucleon**. Generic term for a nuclear constituent, a neutron or proton.

**Nutation**. A displacement of the axis of a spinning body away from the simple cone shaped figure which would be traced by the axis during *precession*. In the *rotating frame of reference*, the nutation caused by an *RF pulse* appears as a simple precession, although the motion is more complex in the stationary frame of reference.

**Nx, Ny, Nz**. The number of sampled points in the x, y, or z direction, respectively.

**Nyquist limit**. *Frequency* of a signal beyond which *aliasing* will occur in the *sampling* process. This frequency is equal to one half the sampling rate.

# O

**Off resonance**. A state occurring when the Larmor frequency of a spin isochromat is different from that of the exciting RF field.

**On resonance**. A state occurring when the Larmor frequency of a spin isochromat is the same as that of the exciting RF field.

**Opposed-phase image**. An image in which the signal from two spectral components (such as fat and water) are 180° out-of-phase and lead to destructive interference in a voxel.

**Orientation**. The three basic orthogonal slice orientations are: transverse (T), sagittal (S) and coronal (C). The basic anatomical directions are: right (R) to left (L), posterior (P) to anterior (A), and feet (F) to head (H), considered as positive directions. The location in the R/L and P/A directions can be specified relative to the axis of the magnet; the F/H location can be specified relative to a convenient patient structure.

A standard display orientation for images in the basic slice orientation is: 1) transverse: A to top of image and L to right, 2) coronal: H to top of image and L to right and 3) sagittal: H to top of image and A to left.

The orientation of single oblique slices can be specified by rotating a slice in one of the basic orientations toward one of the other two basic orthogonal planes about an axis defined by the intersection of the two planes. For example, a plane tipped from the transverse 30˚ toward the sagittal would be denoted T ∅ S 30. Double oblique slices can be specified as the result of tipping a single oblique plane as above toward the remaining basic orientation plane about an axis defined by the intersection of the oblique plane and the remaining basic plane. For example, tipping the single oblique plane above 40˚ toward the coronal would be denoted (T ∅ S 30) ∅ C 40. In double oblique angulations, the first rotation is chosen about the vertical image axis and the second about the (new) horizontal axis. Angles are chosen to have magnitudes less than 90˚ (for single oblique slices less than 45˚); the sign of the angle is taken to be positive when the rotation brings positive axes closer together. For a scan including a family of single oblique angulations in a fan, we keep the same primary slice order to denote all the images, choosing it so the average angle is in the range ±45˚. Labelling the four sides of the image according to the direction relative to the center of the image helps clarify anatomical orientation: the basic orientation images will have four single letter labels, single oblique images will have two single and two double letter labels and double oblique images will have two double and two triple letter labels. The order of the letters in the label should reflect the relative closeness of the primary axes. The slice location can be specified by the location of the point at the center of the slice. In general, the actual displayed image may have a further, in-plane, rotation; this should be indicated either as an angle of rotation (positive, clockwise) or with a graphical icon, as discussed below.

An alternate way to specify the orientation of the image plane is with the direction cosines of the normal to the plane (the cosines of the angle between a line perpendicular to the image plane and the basic axes (A, L, H)). This may be convenient when specifying images to be acquired perpendicular to an axis between anatomical landmarks. The labelling of the locations of the sides of the image relative to the image center would be the same as above for specification of plane orientation by rotations relative to the basic orientation planes.

If available, some graphic aids can be helpful to show image orientations. 1) A graphic icon of the labelled primary axes (A, L, H) with relative lengths given by direction sines and orientation as if viewed from the normal to the image plane can help orient the viewer, both to identify image plane orientation and to indicate possible in-plane rotation. 2) In graphic prescription of obliques from other images, a sample original image with an overlaid line or set of lines indicating the intersection of the original and oblique image planes can help orient the viewer.

# P

**Pacemaker effect**. All implanted electronic devices are susceptible to the fields used in *MR*. The static *magnetic field* applies force to magnetic materials and both *RF* fields and pulsed *gradients* can induce voltages in circuits. The pacemaker's susceptibility to static field and its critical role in life support have warranted special consideration. Transcutaneous control or adjustment of pacing rate is a feature of many units. Some achieve this control using switches activated by the external application of a magnet to open/close the switch. Others use rotation of an external magnet to turn internal controls. The fringe field around an MR magnet can activate such switches or controls. Such activations are considered to be a risk. Areas with fields higher than 0.5 mT (5 G) commonly have restricted access and/or are posted as being a risk to persons with pacemakers.

**Paradoxical enhancement**. See *flow-related enhancement.*

**Parallel imaging.** The use of multiple receiver coils to collect simultaneously different portions of the image in physical space, or different data points in k-space, which are then used to reconstruct collected images. Parallel imaging speeds data collection and therefore decreases total imaging time, with some loss in signal-to-noise ratios compared to conventional imaging and longer post-acquisition reconstruction times. Particular strategies in parallel imaging include vendor-specific methods such as sensitivity-encoding (SENSE, mSENSE), simultaneous acquisition of spatial harmonics (SMASH), generalized auto-calibrating partially parallel acquisition (GRAPPA), integrated parallel acquisition techniques (iPAT), and others. These parallel imaging techniques differ from one another, some requiring collection of a sensitivity map of each receiver coil for use in image reconstruction.

**Paramagnetic**. A substance with a small but positive *magnetic susceptibility* (magnetizability). The addition of a small amount of paramagnetic substance may greatly reduce the *relaxation times* of water. Typical paramagnetic substances usually possess an unpaired electron and include atoms or ions of transition elements, rare earth elements, some metals, and some molecules including molecular oxygen and free radicals. Paramagnetic substances are considered promising for use as *contrast agents* in MR imaging.

**Partial Fourier imaging**. Reconstruction of an image from an MR data set comprising an asymmetric sampling of *k-space*. For example, it can be used either to shorten *image acquisition time*, by reducing the number of *phase encoding* steps required, or to shorten the *echo time, TE*, by moving the *echo* off center in the *acquisition window*. In either case the *signal-to-noise ratio* is reduced and the resolution can be improved to correspond to the maximum available resolution in the data.

**Partial saturation (PS)**. *Excitation* technique applying repeated *RF pulses* in times on the order of or shorter than *T1*. In *MR imaging* systems, although it results in decreased signal amplitude, there is the possibility of generating images with increased *contrast* between regions with different relaxation times. It does *not* directly produce images of T1. The change in *MR signal* from a region resulting from a change in the *interpulse time, TR*, can be used to calculate T1 for the region. Although partial saturation is also commonly referred to as *saturation recovery*, that term should properly be reserved for the particular case of partial saturation in which recovery after each *excitation* effectively takes place from true *saturation*.

**Partial saturation spin echo (PSSE)**. *Partial saturation* in which the signal is detected as a *spin echo*. Even though a spin echo is used, there will not necessarily be a significant contribution of the *T2 relaxation time* to image *contrast*, unless the echo time, *TE*, is on the order of or longer than T2.

**Partial volume effect**. The loss of contrast between two adjacent tissues in an image caused by insufficient *resolution* so that more than one tissue type occupies the same *voxel* (or *pixel*).

**Passive shielding**. *Magnetic shielding* through the use of high *permeability* material (see also *Magnetic shielding*, *Self-shielding* and *Room shielding*).

**Passive shimming**. *Shimming* by adjusting the position of suitable pieces of *ferromagnetic* metal within or around the main magnet of an *MR* system.

**PD.** *See Proton density.*

**Peak**. See *Spectral line.*

Perfusion-weighted imaging. Image acquisition techniques that highlight fluids moving through arteries, veins, and capillaries.

**Permanent magnet.** A magnet whose *magnetic field* originates from permanently magnetized material.

**Permeability (μ).** Tendency of a substance to concentrate *magnetic field*, $\mu = B/H$.

**Phantom**. An artificial object of known dimensions and properties used to test aspects of an imaging machine.

**Phase**. In a periodic function (such as rotational or sinusoidal motion), the position relative to a particular part of the cycle.

**Phase correction**. (1) corrective processing of the *spectrum* so that *spectral lines* at different *frequencies* all have the *absorption-mode phase*. (2) in imaging, adjustment of the signal in different parts of the image to have a consistent phase.

**Phase cycling**. Techniques of signal *excitation* in which the phases of the *exciting* or *refocusing* RF pulses are systematically varied and the resulting signals are then suitably combined in order to reduce or eliminate certain *artifacts*.

**Phase encoding**. Encoding the distribution of sources of *MR signals* along a direction in space with different phases by applying a pulsed *magnetic field gradient* along that direction prior to detection of the signal. In general, it is necessary to acquire a set of signals with a suitable set of different phase-encoding gradient pulses in order to reconstruct the distribution of the sources along the encoded direction.

**Phase encoding order**. The temporal order in which the phase encoding *gradient* pulses are applied. The order can be sequential, centric, reverse centric, random, etc.

**Phase sensitive detector**. *Detector* that measures the *phase* of the signal relative to the phase of a reference oscillator. See *Quadrature detector.*

**PIN diode**. A semiconductor device whose *RF* resistance varies in proportion to an applied DC bias current. PIN diodes are essential elements for rapid switching of RF *coils* between transmit and receive modes and for coil *decoupling*.

**Pixel**. Acronym for a picture element; the smallest discrete part of a digital image display. Note that the corresponding size of the pixel may be smaller than the actual *spatial resolution.*

**Planar imaging**. Imaging technique in which the image of a plane is built up from signals received from the whole plane. See also *Sequential plane imaging*.

**Point spread function (PSF)**. A hypothetical point object will generally have an extended (blurred) image resulting from the imaging process; this is the point spread function characterizing the imaging process. Considering any object as composed of an assembly of point objects, knowledge of the PSF permits the prediction of how the object will be imaged, assuming *linearity* of the imaging process.

**Pole piece (or pole tip)**. High *permeability* material used to shape the uniformity of the useful volume of a *magnet*, especially a *permanent magnet*.

**Population**. The numbers of nuclei or electrons in different *energy levels*. At thermal equilibrium, the relative populations of the energy levels will be given by the *Boltzmann distribution*.

**Preamplifier**. A device that amplifies very low-level signals. A preamplifier is generally placed close to its signal source and has a very low *noise figure* as it is the principal determinant of electronic noise within the system. Preamplifiers used in MR systems usually have a low input impedance, and require a *matching network* to interface to the RF coil, although preamplifiers with high input impedance may be used with surface coils. Such devices typically use a field effect transistor (FET) as their input stage.

**Precession**. Comparatively slow gyration of the axis of a spinning body so as to trace out a cone; caused by the application of a *torque* tending to change the direction of the rotation axis, and continuously directed at right angles to the plane of the torque. The *magnetic moment* of a nucleus with *spin* will experience such a torque when inclined at an angle to the *magnetic field*, resulting in precession at the *Larmor frequency*. Familiar examples are the effect of gravity on the motion of a spinning top, gyroscope, or the rotating earth.

**Precessional frequency**. See *Larmor frequency.*

**Preemphasis**. Means of compensating for the non-ideal response of a system such as the *magnetic field gradient* system by modifying the input function.

**Presaturation**. See *Saturation.*

**Probe**. The portion of an *MR spectrometer* comprising the sample container and the *RF coils*, with some associated electronics. The RF coils may consist of separate *receiver* and *transmitter* coils in a *crossed-coil* configuration, or, alternatively, a single coil to perform both functions.

**Progressive saturation**. See *Saturation recovery.*

**Projection profile**. *Spectrum* of *MR signal* whose *frequency* components are broadened by a *magnetic field gradient*. In the simplest case (negligible *line width*, no *relaxation* effects, and no effects of prior gradients), it corresponds to a one-dimensional projection of the *spin density* along the direction of the gradient; in this form it is used in *projection-reconstruction imaging*.

**Projection-reconstruction imaging**. MR imaging technique in which a set of *projection profiles* of the body is obtained by observing *MR signals* in the presence of a suitable corresponding set of *magnetic field gradients*. Images can then be reconstructed using techniques analogous to those used in conventional computed tomography (CT), such as filtered back projection. It can be used for *volume imaging* or, with plane selection techniques, for *sequential plane imaging*.

**Prospective synchronization**. See *Synchronization*, *prospective.*

Proton density (PD). The quantity of hydrogen nuclei in each voxel or volume of tissue. Spin-echo imaging can generate a proton density-weighted image by using long TR and very short TE settings.

**PS**. See *Partial saturation.*

PSF. *See Point spread function.*

**PSSE**. See *Partial saturation spin echo.*

**Pulse, 90° (π/2 pulse)**. *RF pulse* designed to rotate the *macroscopic magnetization vector* 90° in space as referred to the *rotating frame of reference*, usually about an axis at right angles to the main *magnetic field*. If the spins are initially aligned with the magnetic field, this pulse will produce *transverse magnetization* and an *FID*.

**Pulse, 180° (π pulse)**. *RF pulse* designed to rotate the *macroscopic magnetization vector* 180° in space as referred to the *rotating frame of reference*, usually about an axis at right angles to the main *magnetic field*. If the *spins* are initially aligned with the magnetic field, this pulse will produce *inversion*.

**Pulse, gradient.** See *Gradient pulse*.

**Pulse, RF**. See *RF pulse.*

**Pulse length (width)**. Time duration of a pulse. For an *RF pulse* near the *Larmor frequency*, the longer the pulse length, the greater the angle of rotation of the *macroscopic magnetization vector* will be (greater than 180° can bring it back toward its original orientation). For an RF pulse of a given shape as a function of time, the longer the pulse length, the narrower the equivalent range of frequencies in the pulse will be.

**Pulse NMR**. NMR techniques that use *RF pulses* and *Fourier transformation* of the *NMR signal*; have largely replaced the older *continuous wave* techniques.

**Pulse programmer**. Part of the *spectrometer* or *interface* that controls the timing, duration, *phase*, and amplitude of the *pulses* (*RF* or *gradient*).

**Pulse sequences**. Set of *RF* (and/or *gradient*) *magnetic field pulses* and time spacings between these pulses; used in conjunction with magnetic field gradients and MR signal reception to produce *MR images*. See also *Interpulse times*. A recommended shorthand designation of interpulse times used to generate a particular image is to list the repetition time (*TR*), the echo time (*TE*) and, if using *inversion-recovery*, the inversion time, *TI*, with all times given in milliseconds. For example, 2500/30/1000 would indicate an inversion-recovery pulse sequence with TR of 2500 msec, TE of 30 msec, and TI of 1000 msec. If using multiple *spin echoes*, as in *CPMG*, the number of the spin echo used should be stated.

**Pulsed gradients**. See *Gradient pulse.*

# Q

**Q**. See *Quality factor.*

**Quadrature coil**. A *coil* that produces an *RF* field with circular polarization by providing RF feed points that are out of *phase* by 90°. When used as a transmitter coil a factor of two power reduction over a linear coil results; as a receiver an increase in *SNR* of up to a factor of $\sqrt{2}$ can be achieved.

**Quadrature detector**. A *phase* sensitive *detector* or *demodulator* that detects the components of the signal in phase with a reference signal and 90° out of phase with the reference signal. This may be performed by either analog or digital means.

**Quadrupole moment**. A measure of the non-spherical distribution of electrical charge possessed by nuclei with a *nuclear spin number* greater than 1/2. The resulting interaction with electric field gradients in the molecule can lead to a shortening of *relaxation times* and a broadening of *spectral lines*.

**Quality factor (Q)**. Applies to any resonant circuit component; most often the *coil* Q determines the overall Q of the circuit. Inversely related to the fraction of the energy in an oscillating system lost in one oscillation cycle. Q is inversely related to the range of *frequency* over which the system will exhibit *resonance*. It affects the *signal-to-noise ratio*, because the detected signal increases proportionally to Q while the noise is proportional to the square root of Q. The Q of a coil will depend on the circumstances under which it is measured, e.g., whether is is "unloaded" (no patient) or "loaded" (patient).

**Quantization noise**. See *Digitization noise.*

**Quenching**. Loss of *superconductivity* of the current-carrying *coil* that may occur unexpectedly in a superconducting magnet. As the magnet becomes resistive, heat will be released that can result in rapid evaporation of liquid helium in the *cryostat*. This may present a hazard if not properly planned for.

# R

**R1.** Longitudinal *relaxation rate* equal to reciprocal of relaxation time (R1 = 1/T1).

**R2.** Longitudinal *relaxation rate* equal to reciprocal of relaxation time (R2 = 1/T2).

**ROI.** (See *Region-of-interest*)

**Radian**. Dimensionless unit of angular measure; $360^\circ = 2\pi$ radians.

**Radiofrequency (RF)**. Wave *frequency* intermediate between auditory and infrared. The RF used in *MR* studies is commonly in the *megahertz* (MHz) range. The RF used in *ESR* studies is commonly in the *gigahertz* (GHz) range. The principal effect of RF *magnetic fields* on the body is power deposition in the form of heating, mainly at the surface; this is a principal area of concern for safety limits.

**Ramp time**. Time required for a change in the *magnetic field* strength, usually measured in *tesla*/min; depends on construction of the magnet and design of the magnet power supply.

**Ramping**. Changing the strength of the *magnetic field* of a magnet.

**Random noise**. Noise whose amplitude follows some probability distribution and is uncorrelated.

**Rapid-excitation MR imaging**. There are several approaches to speeding up the MRI data acquisition process by repeating the *excitation* by *RF pulses* in times short compared to *T1*, typically using small *flip angles* and *gradient echo* refocusing. When *TR* is also on the order of or shorter than *T2*, the repeated RF pulses will tend to refocus transverse magnetization remaining from prior excitations, setting up a condition of *steady state free precession*, and a dependence of signal strength (and image contrast) on both T1 and T2. This can be modified in various ways, particularly: 1) "spoil" the tendency to build up a steady state by reducing coherence between excitations, e.g., by variation of the *phase* or timing of consecutive RF pulses or of the strength of *spoiler gradient pulses*, thus increasing the relative dependence of signal strength on T1 or 2) acquire the signal when it is refocusing immediately prior to the next RF pulse, thus increasing the relative dependence of signal strength on T2.

**Raw data**. The digital MR signal sampled and stored during data acquisition. Also referred to as *k-space* data.

**Rayleigh noise**. The distribution associated with the magnitude of the noise amplitude following a Gaussian distribution. The mean value of this distribution is roughly 1.25 $\sigma_0$, where $\sigma_0$ is the standard deviation of the original Gaussian distribution.

**Readout delay**. See *TE.*

**Real signal**. In-phase component of signal detected with a *quadrature detector*.

**Receiver**. Portion of the MR apparatus that detects and amplifies *RF signals* picked up by the *receiving coil*. Includes a *preamplifier*, amplifier, and *demodulator*.

**Receiver coil**. *Coil* of the *RF receiver*; "picks up" the *MR signal*.

**Receiver dead time**. Time after exciting *RF pulse* during which *FID* is not detectable due to saturation of *receiver* electronics.

**Reconstruction from projections imaging**. See *Projection-reconstruction imaging.*

**Reference compound**. Standard compound used as a standard reference *spectral* line for defining *chemical shifts* for a given nucleus. As recommended by the ASTM, for $^{1}$H it is tetramethylsilane (TMS) and for $^{31}$P it is phosphoric acid, although for practical biological applications water and PCr have been used as secondary references for hydrogen and phosphorus spectroscopy, respectively. The reference compound can be in a capsule outside of the subject (external) or can be in the subject (internal); internal references are generally preferable where possible, as external references may be subject to different conditions.

**Refocusing**. See *Spin echo.*

**Refrigerator**. System for actively cooling structures in a *superconducting magnet*. If only *cryoshields* are cooled (two-stage refrigerator), no liquid nitrogen will be needed and He-boil-off will be reduced. If additionally the superconducting coil support is actively cooled (three-stage refrigerator) the He-consumption can be essentially reduced to zero.

**Region-of-interest (ROI).** A user-defined subset of pixels in a planar image.

Relaxation. The return of an excited system of spinning magnetic dipoles (spins) to its equilibrium state.

**Relaxation rates**. Reciprocals of the *relaxation times*, *T1* and *T2* (*R1* = 1/T1 and *R2* = 1/T2). There is often a linear relation between the concentration of MR *contrast agents* and the resulting change in relaxation rate.

**Relaxation times**. After *excitation*, the *spins* will tend to return to their equilibrium distribution, in which there is no *transverse magnetization* and the *longitudinal magnetization* is at its maximum value and oriented in the direction of the static *magnetic field*. It is observed that in the absence of applied *RF magnetic field*, the transverse magnetization decays toward zero with a characteristic time constant *T2*, and the longitudinal magnetization returns toward the equilibrium value $M_o$ with a characteristic time constant *T1*.

**Repetition time**. See *TR.*

**Rephasing gradient**. *Magnetic field gradient pulse* applied to reverse the spatial variation of *phase* of *transverse magnetization* caused by a *dephasing gradient*. For example, in *selective excitation*, it is a magnetic field gradient applied for a brief period after a selective excitation pulse, in the opposite direction to the gradient used for the selective excitation. The result of the gradient reversal is a rephasing of the *spins* (which will have gotten out of phase with each other along the direction of the selection gradient), forming a *gradient echo* and improving the sensitivity of imaging after the selective excitation process.

**Resistive magnet**. A magnet whose *magnetic field* originates from current flowing through an ordinary (nonsuperconducting) conductor.

**Resolution element**. Size of smallest *spatially resolved* regions in image. It may be anisotropic, e.g., with an asymmetric *acquisition matrix* or *slice thickness*, and may be larger than the *pixel* or *voxel*.

**Resolution, spatial**. See *Spatial resolution.*

**Resonance**. A large amplitude vibration in a mechanical or electrical system caused by a relatively small periodic stimulus with a *frequency* at or close to a natural frequency of the system; in *MR* apparatus, resonance can refer to the NMR itself or to the tuning of the *RF* circuitry.

**Resonance frequency**. *Frequency* at which *resonance* phenomenon occurs; given by the *Larmor equation* for *NMR*; determined by inductance and capacitance for *RF* circuits.

**Resonance offset (β)**. Either the phase gDBTR due to an applied field or field inhomogeneity (DB) and generated during the time between two RF pulses, or the phase change of the RF pulse from one pulse to the next.

**Respiratory gating**. See *gating*.

**Respiratory ordering of phase encoding**. Respiratory *synchronization* that acquires image data at regular times independent of the respiratory cycle, but chooses the sequence of *phase encoding* data acquisition so as to minimize the respiratory motion-induced *artifacts* in the resulting image. For example, choosing the sequence of phase encoding such that adjacent samples in the final full data set have minimal differences in respiratory phase will minimize the spacing of "ghost" artifacts in the final image.

**Retrospective respiratory gating**. The resorting of data collected over several acquisitions to create an image where all phase encoding lines are acquired with the object at the same spatial location of the respiratory cycle.

**Retrospective synchronization**. See *Synchronization, retrospective.*

**RF**. See *Radiofrequency*.

**RF coil**. *Coil* used for transmitting *RF pulses* and/or receiving *MR signals*. Commonly used in *birdcage coil, saddle coil,* or *solenoid coil* configurations for *MR imaging*.

**RF pulse.** Burst of *RF magnetic field* delivered to object by *RF transmitter*. For *RF frequency* near the *Larmor frequency*, it will result in rotation of the *macroscopic magnetization vector* in the *rotating frame of reference* (or a more complicated nutational motion in the stationary frame of reference). The amount of rotation will depend on the strength and duration of the RF pulse; commonly used examples are *90°* ($\pi/2$) and *180°* ($\pi$) *pulses*.

**RF shielding**. Electrically conducting shielding designed to isolate an MR system from its environment at the *resonant frequencies* of interest.

**RF spin echo**. *Spin echo* produced by an *RF pulse*.

**RF spoiling**. The use of varying *phase* or timing of the *RF pulses* to prevent setting up a condition of *steady state free precession*, e.g., in *rapid-excitation MR imaging*.

**Room shielding**. *Magnetic shielding* through the use of high *permeability* material in the walls (plus floor and ceiling) of the magnet room. Room shielding can be complete (e.g., six sides of a box), or partial if the *fringe field* is to be reduced only in certain areas (see also *magnetic shielding*).

**Rotating frame of reference.** A frame of reference (with corresponding coordinate systems) that is rotating about the axis of the static *magnetic field* $B_0$ (with respect to a stationary ("laboratory") frame of reference) at a *frequency* equal to that of the applied *RF* magnetic field, $B_1$. Although $B_1$ is a rotating vector, it appears stationary in the rotating frame, leading to simpler mathematical formulations.

**Rotating frame zeugmatography**. Technique of *MR imaging* that uses a *gradient* of the *RF excitation* field (to give a corresponding variation of the *flip angle* along the gradient as a means of encoding the spatial location of spins in the direction of the RF field gradient) in conjunction with a static *magnetic field gradient* (to give spatial encoding in an orthogonal direction). It can be considered to be a form of *Fourier transform imaging*.

# S

**Saddle coil**. *RF coil* configuration design commonly used when the static *magnetic field* is coaxial with the axis of the coil along the long axis of the body (e.g., *superconducting magnets* and most *resistive magnets*) as opposed to *solenoid* or *surface coil*.

**Safety**. Safety concerns in MR include *magnetic field* strength, *RF* heating (*SAR*) induced currents due to rapidly varying magnetic fields (*dB/dt*), effects on implanted devices such as *pacemakers*, magnetic *torque* effects on indwelling metal such as clips and possible "missile effect" of *magnetic forces*, and *acoustic noise*.

**Sagittal plane.** The plane which is defined by the head-to-foot and anterior-to-posterior directions in the human body. A stack of images acquired in the sagittal plane separates images by their left-to-right locations. The mid-line sagittal plane bisects the left and right half of the human body. See also *Orientation*.

**Sampling**. Conversion of the continuous (analog) signal to a series of discrete (digital) values by measurement at a set of particular times; this utilizes the *analog to digital converter*. If the rate of sampling is less than twice the highest frequency in the signal, *aliasing* will occur. The duration of sampling determines how small a difference of frequencies can be separated.

**Sampling window**. See *Acquisition window*.

**SAR**. See *Specific Absorption Rate.*

**Saturation**. A nonequilibrium state in *MR*, in which equal numbers of spins are aligned against and with the *magnetic field*, so that there is no net *magnetization*. Can be produced by repeatedly applying *RF* pulses at the *Larmor frequency* with interpulse times short compared to *T1*.

**Saturation pulses**. Sequence of *RF* (and *gradient*) pulses designed to produce saturation, typically in a selected region or set of regions, most often by the use of *selective excitation* followed by a *spoiler pulse*. Similar to some spectral *suppression techniques*. Can be used to reduce signal from flowing blood by saturating regions upstream from region being imaged.

**Saturation recovery (SR)**. Particular type of *partial saturation pulse sequence* in which the preceding pulses leave the *spins* in a state of *saturation*, so that recovery at the time of the next pulse has taken place from an initial condition of no *magnetization*.

**Saturation transfer (or Inversion transfer)**. Nuclei can retain their magnetic orientation through a chemical reaction. Thus, if *RF* radiation is supplied to the *spins* at a *frequency* corresponding to the *chemical shift* of the nuclei in one chemical state so as to produce *saturation* or *inversion*, and chemical reactions transform the nuclei into another chemical state with a different chemical shift in a time short compared to the *relaxation time*, the NMR *spectrum* may show the effects of the saturation or inversion on the corresponding, unirradiated, line in the spectrum. This technique can be used to study reaction kinetics of suitable molecules.

**Scalar**. A quantity having only magnitude.

**SE**. See *Spin echo.*

**Segmented k-space data acquisition**. A set of *k-space* lines collected in a specified order but not constituting a complete coverage of k-space. Several segmental acquisitions may need to be run for complete coverage of k-space. For example, rapidly acquiring eight k-space lines per segment after each trigger until 128 lines of k-space are acquired in 16 triggers.

**Selective excitation**. Controlling the *frequency spectrum* of an irradiating *RF pulse* (via *tailoring*) while imposing a *magnetic field gradient* on *spins*, such that only a desired region will have a suitable *resonant frequency* to be excited. Originally used to excite all but a desired region; now more commonly used to select only a desired region, such as a plane, for excitation. Used without simultaneous *magnetic field* gradients, tailored RF pulses can be used to selectively excite a particular *spectral line* or group of lines. RF and gradient pulse combinations can be designed to select both spatial regions and spectral frequencies.

**Selective irradiation**. See *Selective excitation.*

**Self-shielding**. *Magnetic shielding* by attaching a high *permeability yoke* to the magnet (*passive shielding*) or by incorporating additional magnetic field-generating *coils* designed to reduce the external field (*active shielding*). See also *Magnetic shielding.*

**Sensitive plane**. Technique of selecting a plane for *sequential plane imaging* by using an oscillating magnetic field *gradient* and filtering out the corresponding time dependent part of the *MR signal*. The gradient used is at right angles to the desired plane and the magnitude of the oscillating magnetic field gradient is equal to zero only in the desired plane.

**Sensitive point**. Technique of selecting out a point for sequential point imaging by applying three orthogonal oscillating *magnetic field gradients* such that the local *magnetic field* is time-dependent everywhere except at the desired point, and then filtering out the corresponding time dependent portion of the *MR signal*.

**Sensitive volume**. Region of the object from which *MR signal* will preferentially be acquired because of strong *magnetic field inhomogeneity* elsewhere. Effect can be enhanced by use of a shaped *RF* field that is strongest in the sensitive region.

**Sequence time**. See *TR*..

**Sequential line imaging (Line scanning, Line imaging)**. *MR imaging* techniques in which the image is built up from successive lines through the object. In various schemes, the lines are isolated by oscillating *magnetic field gradients* or *selective excitation*, and then the *MR signals* from the selected line are encoded for position by detecting the *FID* or *spin echo* in the presence of a magnetic field gradient along the line; the *Fourier transform* of the detected signal then yields the distribution of emitted MR signal along the line.

**Sequential plane imaging (Planar imaging)**. *MR imaging* technique in which the image of an object is built up from successive planes in the object. In various schemes, the planes are selected by oscillating *magnetic field gradients* or *selective excitation.*

**Sequential point imaging (Point scanning)**. *MR imaging* techniques in which the image is built from successive point positions in the object. In various schemes, the points are isolated by oscillating *magnetic field gradients* (sensitive point) or shaped *magnetic fields*.

**SFP**. See *Steady state free precession.*

**Shaped pulse**. See *Tailored pulse.*

**Shielded gradient coils**. Current-carrying *gradient coils* with reduced gradient fringe field inside of the magnet cryostat structures like *cryoshields* and He-vessel. The shielding can be accomplished by secondary actively driven coils or by passive screens which are inductively coupled to the gradient coils. In both cases *eddy currents* outside of the gradient system will be reduced.

**Shielding**. See *Magnetic shielding*, *Cryoshielding*, *RF shielding,* or *Faraday shield*.

**Shift reagents**. *Paramagnetic* compounds designed to induce a shift in the *resonance frequency* of nuclei with which they interact. For example, many rare earths have been used as shift reagents for positive metal ions such as sodium and potassium.

**Shim coils**. *Coils* carrying a relatively small current that are used to provide auxiliary *magnetic fields* in order to compensate for *inhomogeneities* in the main magnetic field of an *MR* system.

**Shimming**. Correction of *inhomogeneity* of the *magnetic field* produced by the main magnet of an *MR* system due to imperfections in the magnet or to the presence of external *ferromagnetic* objects. May involve changing the configuration of the magnet or the addition of *shim coils* (*active shimming*) or small pieces of steel (*passive shimming*).

**SI (International System of Units).** The preferred international standard system of physical units and measures.

**Signal averaging**. The averaging together of signals acquired under the same or similar conditions so as to suppress the effects of random variations or random artifacts. The number of signals averaged together can be abbreviated *NSA*.

**Signal-to-noise ratio (SNR or S/N).** Used to describe the relative contributions to a detected signal of the true signal and random superimposed signals ("*noise*"). One common method to improve (increase) the SNR is to average several measurements of the signal on the expectation that random contributions will tend to cancel out. The SNR can also be improved by sampling larger volumes (with a corresponding loss of spatial resolution) or, within limits, by increasing the strength of the magnetic field used. *Surface coils* can also be used to improve local SNR. The SNR will depend, in part, on the electrical properties of the sample or patient being studied.

**Signal suppression**. The elimination or reduction of a particular signal by, for example, the application of a narrow band *frequency*-selective preparation pulse centered at the *resonant* frequency of the signal. This can also be accomplished using an *inversion recovery* technique to null the signal as it recovers its longitudinal magnetization.

**Sinc interpolation**. A method of interpolating image data by *zero filling* the high spatial-frequency components of the raw data so that after Fourier transformation the image matrix size has been increased. This method can significantly improve the image display.

**Single-shot imaging.** The process of acquiring all data needed to form a two-dimensional image with a single excitation pulse. *Echo-planar imaging* is an example of single-shot imaging.

**Skin depth**. Time-dependent electromagnetic fields are significantly attenuated by conducting media (including the human body); the skin depth gives a measure of the average depth of penetration of the *RF* field. It may be a limiting factor in *MR imaging* at very high frequencies (high magnetic fields). The skin depth also affects the *Q* of the *coils*.

**Slice**. The effective physical extent of the "planar" region being imaged.

**Slice profile**. The spatial distribution of sensitivity of the imaging process in the direction perpendicular to the plane of the *slice*. When the profile deviates appreciably from rectangular, the *slice thickness* alone may not provide an adequate description.

**Slice selection.** The excitation of spins in a limited planar section of tissue by applying a gradient (the slice-selective gradient) while sending a narrow-band radiofrequency pulse of appropriate frequencies into the subject.

**Slice thickness**. The thickness of a *slice*. As the *slice profile* may not be sharp edged, a criterion such as the distance between the points at half the sensitivity of the maximum (*FWHM*) or the equivalent rectangular width (the width of a rectangular slice profile with the same maximum height and same area) may be useful.

**S/N**. See *Signal-to-noise ratio.*

**SNR**. See *Signal-to-noise ratio.*

**Solenoid coil**. A coil of wire wound in the form of a long cylinder. When a current is passed through the coil, the *magnetic field* within the coil is relatively uniform. Solenoid *RF coils* are commonly used when the static magnetic field is perpendicular to the long axis of the body.

**Solvent suppression**. See *Suppression.*

**Spatial frequency**. A dimension of the *Fourier transform* space (*k-space* representation of an image), having units of inverse distance. Higher values of spatial frequencies correspond to finer detail in the image.

**Spatial resolution**. The smallest distance between two points in the object that can be distinguished as separate details in the image, generally indicated as a length or a number of black and white line pairs per mm. The specific criterion for resolution to be used depends on the type of test used (e.g., bar pattern or contrast-detail *phantom*). As the ability to separate or detect objects depends on their *contrast* and the *noise*, and the different *MR* parameters of objects will affect image contrast differently for different imaging techniques, care must be taken in comparing the results of resolution phantom tests of different machines and no single simple measure of resolution can be specified. The resolution may be anisotropic.

The resolution may be larger than the size corresponding to the discrete image element (*pixel*), although it cannot be smaller.

**Spatially localized spectroscopy**. Process by which regions of tissue are selectively sampled to produce *spectra* from defined volumes in space. These methods may be employed to sample a single region in space (single voxel method) or multiple regions simultaneously (multivoxel methods). The spatial selectivity can be achieved by a variety of methods including *surface coils*, surface coils in conjunction with *RF gradient* methods, or RF pulses in combination with switched *magnetic field* gradients, for example, *volume-selective excitation*. An indirect method of achieving spatial selectivity is the destruction of coherence of the *magnetization* in regions that lie outside the region of interest. A variety of spatial encoding schemes have been employed for multivoxel localization. See *Chemical shift imaging*.

**Spatial-spectral (or spectral-spatial) excitation.** Excitation that is both spatially and spectrally selective. This is generally accomplished by using composite excitation, with $180^o$ phase cycling between water and fat ($CH_2$) magnetization during the inter-pulse intervals. For example, selective excitation of water in an image slice can be accomplished at 1.5T using a 1-2-1 composite pulse, consisting of a combination of $22.5^o$, $45^o$, and $22.5^o$ pulses, with about 2.25 msec between each. This will impart $90^o$ excitation to water and no excitation to fat.

**Specific absorption rate (SAR) (W/kg)**. Time varying electromagnetic fields can deposit energy in tissues. This energy is deposited mostly in the form of heat which is considered the primary mechanism of biological effect. The specific absorption rate (SAR) is defined as the energy dissipated in tissue (watts) per kilogram of tissue mass. Inhomogeneity of the *RF* fields leads to a local exposure where most of the power that is absorbed is applied to one body region rather than the entire person, leading to the concept of a local SAR. Averaging over the whole body leads to the global SAR.

**Spectral editing**. Methods of selectively enhancing or suppressing the signal from a particular molecular substance by using its spin properties, typically through spin-spin coupling, e.g., *J-modulation*.

**Spectral line**. Particular distinct *frequency* or narrow band of frequencies at which *resonance* occurs corresponding to a particular *chemical shift*.

**Spectral width**. The overall width in *hertz* needed to observe a particular *NMR spectrum*. This width is generally set using the *Nyquist limit*; namely, that the temporal sampling rate must be equal to twice the maximum spread in frequencies.

**Spectrometer**. The portions of the *MR* apparatus that actually produce the NMR phenomenon and acquire the signals, including the *magnet*, the *probe*, the *RF* circuitry, the *gradient coils*, etc. The spectrometer is controlled by the rom via the *interface* under the direction of the rom.

**Spectroscopy**. See *Magnetic resonance spectroscopy*.

**Spectroscopic imaging.** MR techniques that permit acquisition of an MR spectrum for each pixel or voxel in the MR image**.** The resulting acquired data can then be presented as an MR spectrum for each pixel or voxel or as an image or set of images that reflects the intensity of a particular spectral peak at each spatial location in two- or three-dimensions.

**Spectrum**. An array of the *frequency components of the MR signal* according to frequency. Nuclei with different *resonant frequencies* will show up as values at different corresponding frequencies in the spectrum. When resonances are relatively isolated they appear as peaks or “lines” in the spectrum.

**Spin**. The intrinsic *angular momentum* of an elementary particle, or system of particles such as a nucleus, that is also responsible for the *magnetic moment*; or, a particle or nucleus possessing such a spin. The spins of nuclei have characteristic fixed values. Pairs of neutrons and protons align to cancel out their spins, so that nuclei with an odd number of neutrons and/or protons will have a net nonzero rotational component characterized by an integer or half integer quantum "*nuclear spin number*" (*I*).

**Spin density (N)**. The density of resonating *spins* in a given region; one of the principal determinants of the strength of the *MR signal* from the region. The *SI* units would be moles/$m^3$. For water, there are about 1.1 x $10^5$ moles of hydrogen per $m^3$, or .11 moles of hydrogen/$cm^3$. True spin density is *not* imaged directly, but must be calculated from signals received with different *interpulse times*.

**Spin echo (SE)**. The *RF pulse sequence* where a 90° excitation pulse is followed by a 180° refocusing pulse to eliminate field *inhomogeneity* and *chemical shift* effects at the echo. RF spin echo would be a more appropriate name.

**Spin echo imaging**. Any of many *MR imaging* techniques in which the *spin echo* is used rather than the *FID*. Can be used to create images that depend strongly on *T2* if TE has a value on the order of or greater than T2 of the relevant image details. Note that spin echo imaging does *not* directly produce an image of T2 distribution. The spin echoes can be produced as a train of multiple echoes, e.g., using the *CPMG pulse sequence*.

**Spin-lattice relaxation time**. See *T1*.

**Spin number, nuclear**. See *Spin quantum number.*

**Spin quantum number (I).** Property of all nuclei related to the largest measurable component of the nuclear *angular momentum*. Non-zero values of nuclear angular momentum are quantized (fixed) as integral or half-integral multiples of (h/2π), where h is Planck's constant. The number of possible *energy levels* for a given nucleus in a fixed *magnetic field* is equal to 2I + 1. Similarly, an unpaired electron has a spin of 1/2 and two possible energy levels.

**Spin-spin coupling**. MR *spectral lines* may consist of groups of lines called *multiplets*. This multiplet structure is caused by interactions between nuclei that split the NMR *energy levels* and result in the observation of multiple allowed *transitions* separated by an amount of energy related to *J*, the spin-spin *coupling constant.* These interactions are called spin-spin coupling.

**Spin-spin relaxation time**. See *T2.*

**Spin tagging**. A method used to trace the motion or flow of tissue. Nuclei will retain their magnetic orientation for a time on the order of T1 even in the presence of motion. Thus, if the nuclei in a given region have their spin orientation changed, the altered spins will serve as a "tag" to trace the motion for a time on the order of T1 of any fluid that may have been in the tagged region.

**Spin warp imaging**. A form of *Fourier transform imaging* in which phase-encoding *gradient* pulses are applied for a constant duration but with varying amplitude. The spin warp method, as other Fourier imaging techniques, is relatively tolerant of nonuniformities (*inhomogeneities*) in the *magnetic fields*.

**Spiral k-space coverage**. Acquisition of data whose views cover a spiral in *k-space*. It is accomplished by applying an oscillatory *gradient* which increases in amplitude as a function of time.

**Spoiler gradient pulse**. Magnetic field *gradient* pulse applied to effectively remove *transverse magnetization* by producing a rapid variation of its *phase* along the direction of the gradient. For example, when used to remove the unwanted signal resulting from an imperfect 180° *refocusing RF pulse*, a corresponding compensating gradient pulse may be applied prior to the refocusing RF pulse in order to avoid spoiling the desired transverse magnetization resulting from the initial *excitation*. Also called homospoil pulse.

**SR**. See *Saturation recovery.*

**SSFP**. See *Steady state free precession.*

**Steady-state coherent**. A state of *spins* which leads to an equilibrium *magnetization* for the longitudinal and transverse magnetization, or, when the magnetization at, or after, each *RF* pulse is the same as in the previous pulse.

**Steady state free precession (SFP or SSFP)**. Method of *MR excitation* in which strings of *RF pulses* are applied rapidly and repeatedly with interpulse intervals short compared to both *T1* and *T2*. Alternating the *phases* of the RF pulses by 180° can be useful. The MR signal reforms as an *echo* immediately before each RF pulse; immediately after the RF pulse there is additional signal from the *FID* produced by the pulse. The strength of the FID will depend on the time between pulses (*TR*), the magnetization of the tissue, and the *flip angle* of the pulse; the strength of the echo will additionally depend on the T2 of the tissue. SSFP may be used as a means of *rapid-excitation MR imaging*. With the use of appropriate *dephasing gradients*, the signal can be observed as a *frequency-encoded gradient echo* either shortly before the RF pulse or after it; the signal immediately before the RF pulse will be more highly T2-weighted. The signal immediately after the RF pulse in a rapid series of RF pulses will depend on T2 as well as T1 unless measures are taken to destroy signal refocusing and prevent the development of steady state free precession. To avoid setting up a state of SSFP when using rapidly repeated excitation RF pulses, it may be necessary to spoil the phase coherence between excitations, e.g., with varying *phase* shifts or timing of the exciting RF pulses or varying *spoiler gradient* pulses between the excitations.

**Stimulated echo**. A form of *spin echo* produced by three-pulse *RF* sequences, consisting of two RF pulses following an initial exciting RF pulse. The stimulated echo appears at a time delay after the third pulse equal to the interval between the first two pulses. Although classically produced with 90° pulses, any RF pulses other than an ideal 180° can produce a stimulated echo. The intensity of the echo depends in part on the *T1 relaxation time* because the excitation is "stored" as *longitudinal magnetization* between the second and third RF pulses. For example, use of stimulated echoes with *spatially selective* excitation with orthogonal *magnetic field gradients* permits *volume-selective excitation* for spectroscopic localization.

**Superconducting magnet**. A magnet whose *magnetic field* originates from current flowing through a *superconductor*. Such a magnet must be enclosed in a *cryostat*.

**Superconductor**. A substance whose electrical resistance essentially disappears at temperatures near absolute zero. A commonly used superconductor in *MR imaging* system magnets is niobium-titanium, embedded in a copper matrix to help protect the superconductor from *quenching*.

**Suppression**. One of a number of techniques designed to minimize the contribution of a particular component of the object to the detected *signal*. For example, commonly used to suppress the strong signal from water in order to detect spectral line from other components.

**Surface coil**. *Receiver coil* that does not surround the body and is placed close to the surface of the body. Used to restrict the region of the body contributing to the detected signal. As only the region close to the surface coil will contribute to the noise, there may be an improvement in the *signal-to-noise ratio* for regions close to the coil, compared to the use of receiver coils that surround the corresponding part of the body.

**Surface coil MR**. A *surface coil* placed over a region of interest will have an effective selectivity for a volume approximately subtended by the coil circumference and one radius deep from the coil center. Such a coil can be used for simple localization of sites for measurement of chemical shift spectra, especially of phosphorus, and blood flow studies. Some additional spatial selectivity can be achieved with *magnetic field gradients*.

**Susceptibility**. See *Magnetic susceptibility.*

**Susceptibility artifact**. The loss of MR signal in voxels or regions with varying magnetic susceptibility (magnetic non-uniformities) due to greater T2* decay. Susceptibility artifacts are more obvious in pulse sequences weighted more heavily by T2* effects, such as gradient-echo imaging.

**Switchable coil**. An *RF array coil* consisting of several separately resonant elements, any one of which can be selected as the receiver coil at a particular time. Coils not in use are *decoupled*. Applications of switchable coils include imaging the whole spine without patient repositioning (where the coil elements may collectively be known as a ladder coil), imaging of bilateral structures such as TMJ or orbit using separate coils, or imaging using a coil with selectable field-of-view.

**Synchronization, cardiac**. Acquiring images of particular phases of the cardiac cycle, through either *retrospective* or *prospective synchronization*. Also sometimes called cardiac *gating*.

**Synchronization, prospective**. Controlling the timing or sequence of image data acquisition according to the phase of respiratory or cardiac cycles. See also *Triggering.*

**Synchronization, respiratory**. The respiratory phase can be used to control imaging either by only acquiring the image data during a particular portion of the respiratory cycle (which increases *image acquisition time*) or by adjusting the sequence of image data collection according to the phase of the respiratory cycle in such a way as to minimize motion-induced artifacts in the reconstructed image. See also *Respiratory ordering of phase encoding.*

**Synchronization, retrospective**. Sorting and possibly adjusting image data acquired asynchronously with the cardiac or respiratory cycle, according to the phase of the cycle at which it was acquired, so as to reconstruct a set of images corresponding to different phases of the cycle. See also *retrospective respiratory gating*.

# T–U

**T**. See *Tesla.*

**$T_1$ or T1 ("T-one")**. Spin-lattice or longitudinal *relaxation time*; the characteristic time constant for *spins* to tend to align themselves with the external *magnetic field*. Starting from zero *magnetization* in the z direction, the z magnetization will grow to 63% of its final maximum value in a time T1.

**T1-weighted (T1W).** Often used to indicate an image where most of the contrast between tissues or tissue states is due to differences in tissue *T1*. This term may be misleading in that the potentially important effects of tissue density differences and the range of tissue T1 values are ignored. A T1 contrast state is approached by imaging with a TR short compared to the longest tissue T1 of interest and *TE* short compared to tissue *T2* (to reduce T2 contributions to image contrast). Due to the wide range of T1 and T2 and tissue density values that can be found in the body, an image that is T1-weighted for some tissues may not be so for others.

**$T_2$ or T2 ("T-two").** Spin-spin or transverse *relaxation time*; the characteristic time constant for loss of *phase* coherence among spins oriented at an angle to the static *magnetic field*, due to interactions between the spins, with resulting loss of *transverse magnetization* and *MR signal*. Starting from a nonzero value of the magnetization in the xy plane, the xy magnetization will decay so that it loses 63% of its initial values in a time T2, if relaxation is characterized by a simple single exponential decay.

**T2* ("T-two-star")**. The observed time constant of the *FID* due to loss of *phase* coherence among spins oriented at an angle to the static *magnetic field*, commonly due to a combination of magnetic field *inhomogeneities*, $\Delta B$, and *spin-spin transverse relaxation* with resultant more rapid loss in transverse magnetization and *MR signal.* MR signals can usually still be recovered as a spin echo in times less than or on the order of T2. $1/T2^* \cong 1/T2 + \Delta\omega/2$; $\Delta\omega = \gamma\Delta B$. Note that the FID will generally not be an exponential, so that T2* will not be unique.

**T2-weighted (T2W)**. Often used to indicate an image where most of the contrast between tissues or tissue states is due to differences in tissue *T2*. This term may be misleading in that the potentially important effects of tissue density differences and the range of tissue T2 values are often ignored. A T2 contrast state is approached by imaging with a *TR* long compared to tissue *T1* (to reduce T1 contribution to image contrast) and a *TE* between the longest and shortest tissue T2s of interest. A TR greater than 3 times the longest T1 is required for the T1 effect to be less than 5%. Due to the wide range of T1 and T2 and tissue density values that can be found in the body, an image that is T2-weighted for some tissues may not be so for others.

**TAD**. Duration of *acquisition window* (time of *analog to digital conversion*).

**Tagging**. See *Spin tagging.*

**Tailored excitation**. See *Selective excitation.*

**Tailored pulse**. Shaped pulse whose magnitude (and possibly phase) is varied with time in a predetermined manner. Affects the *frequency* components of an *RF pulse* in a manner determined by the *Fourier transform* of the pulse.

**TD**. Difference in time of formation of *RF spin echo* (TER) and *gradient echo* (TE).

**TE**. Echo time. Time between middle of exciting (e.g., 90°) *RF pulse* and middle of *spin echo* production. For multiple echos, use TE1, TE2, etc. When the *RF spin echo* and *gradient echo* are not coincident in time, TE refers to the time of the gradient spin echo.

**Temporal resolution**. The shortest time duration between two events that can be measured with an MR experiment.

**TER**. Time of formation of *RF spin echo*, when adjusted to be different from gradient spin echo.

**Tesla (T)**. The preferred (*SI*) unit of magnetic flux density. One tesla is equal to 10,000 *gauss*, the older (CGS) unit.

**Thermal equilibrium**. A state in which all parts of a system are at the same effective temperature, in particular where the relative alignment of the *spins* with the *magnetic field* is determined solely by the thermal energy of the system (in which case the relative numbers of spins with different alignments will be given by the *Boltzmann distribution*).

**Three-dimensional Fourier transform imaging (3DFT)**. A form of *Fourier transform imaging* in which an entire volume of data is collected simultaneously. This form of Fourier transform imaging requires phase-encoding to be used to separate individual planar sections within the volume, in addition to phase-encoding and frequency encoding in the two orthogonal directions. 3DFT imaging eliminates gaps or low signal areas between individual "slices" and generally has higher signal-to-noise ratios than 2DFT imaging. *See* also *Volume imaging*.

**TI**. Inversion time. In *inversion recovery*, time between middle of *inverting (180°) RF pulse* and middle of the subsequent *exciting (90°)* pulse to detect amount of *longitudinal magnetization*.

**Time-of-flight**. When the local magnetization of moving tissue or fluid is selectively altered in a region, e.g., by *selective excitation*, it will carry the altered magnetization with it when it moves, thus *tagging* the selected region for times on the order of the *relaxation times*. This is the source of several *flow effects*.

**Tip angle**. See *Flip angle*.

**Torque**. A *vector* quantity given by the vector product of the force and the position vector where the force is applied; for a rotating body, the torque is the product of the moment of inertia and the resulting angular acceleration.

**TR**. Repetition time. The period of time between the beginning of a *pulse sequence* and the beginning of the succeeding (essentially identical) pulse sequence.

**Transaxial plane.** The plane perpendicular to long axis of the human body (head-to-foot). Acquiring images in the transaxial plane acquires a stack of parallel images in the head-to-foot direction. Sometimes referred to as the "axial plane" or "transverse plane". See also *Orientation*.

**Transmit/receive (T/R) coil**. An *RF coil* that acts as both a transmitter (T) producing the *$B_1$ excitation field*, and as a receiver (R) of the MR signal. Such a coil requires a T/R switching circuit to switch between the two modes. A body coil is typically a T/R coil, but smaller volume T/R coils (head/extremities) are often used at high field as a means of reducing RF power absorption.

**Transmitter**. Portion of the *MR* apparatus that produces RF current and delivers it to the transmitting *coil*.

**Transmitter coil**. *Coil* of the *RF transmitter*, used in *excitation* of the *spins*.

**Transverse magnetization ($M_{xy}$)**. Component of the *macroscopic magnetization vector* at right angles to the static *magnetic field ($B_0$)*. *Precession* of the *transverse magnetization* at the *Larmor frequency* is responsible for the detectable *MR signal*. In the absence of externally applied *RF magnetic field*, the transverse magnetization will decay to zero with a characteristic time constant of *T2* or *T2**.

**Transverse plane.** The plane perpendicular to long axis of the human body (head-to-foot). Sometimes referred to as the "*transaxia planel*" or "axial plane". See also *Orientation*.

**Transverse relaxation.** The loss of magnetization in the plane perpendicular to the static magnetic field, $\mathbf{B_o}$.

**Transverse relaxation time**. See *T2*.

**Traveling saturation pulse**. A *saturation pulse* which moves from one spatial location to another for each *RF* pulse excitation or each MR slice acquired.

**Trigger delay time**. The time after *triggering* at which data acquisition takes place.

**Triggering**. Generation of an electrical pulse, upon detection of a physiological signal, that can be used to initiate a *synchronized* data-acquisition *pulse sequence*.

**Truncation artifact**. Artifactual ripples adjacent to edges in an image or sharp features in a spectrum, caused by omission of higher frequency terms in *Fourier transform*, particularly with the use of *zero filling* to replace unsampled higher frequencies. See also *apodization* and *Gibbs phenomenon.*

**Two dimensional Fourier transform imaging (2DFT)**. A form of *sequential plane imaging* using *Fourier transform imaging*.

**Tuning**. Process of adjusting the *resonant frequency*, e.g., of the *RF* circuit, to the desired value, e.g., the *Larmor frequency*. More generally, the process of adjusting the components of the *spectrometer* for optimal performance, including *matching* impedances.

**Twister gradient**. A *gradient* pulse designed to dephase low *spatial-frequency* components in an image. The simplest such design is to choose the gradient strength so that a linear phase change of $-\pi$ to $\pi$ is generated across the image.

**Two-dimensional MR**. Form of *MR spectroscopy* in which an additional dimension is added to the conventional *chemical shift* dimension by allowing varying amounts of different interactions between spin systems (such as *NOE, spin-spin coupling* or exchange).

# V

**Variable flip angle**. The temporal variation of *flip angle* (from one *RF pulse* to the next) to enhance *SNR*, and/or equalize the signal intensity for each *phase encoding* step.

**Variable TE**. The variation of *echo time* from one *RF pulse* to the next.

**Variable TR**. The variation of *repetition time* from one *RF pulse* to the next.

**Vector**. A quantity having both magnitude and direction, frequently represented by an arrow whose length is proportional to the magnitude and with an arrowhead at one end to indicate the direction.

**Velocity compensation**. See *gradient moment nulling*.

**Vessel tracking**. An image post processing method to separate vessels from surrounding tissue.

**View**. The ensemble of *raw data* points collected during the signal readout. For example, during Cartesian sampling, normally used to refer to data collected with a fixed value of the phase encoding gradient. Also referred to as one line of k-space. In projection reconstruction, the line is radially oriented, while in spiral imaging, it is a spiral.

**VOI.** *See volume of interest.*

**Volume coil**. *RF coil* that surrounds a portion of the body.

**Volume of interest (VOI).** A user-selected subset of voxels in a three-dimensional dataset.

**Volume imaging**. Imaging techniques in which *MR signals* are gathered from the whole object volume to be imaged at once, with appropriate encoding *pulse RF and gradient sequences* to encode positions of the *spins*. Many *sequential plane imaging* techniques can be generalized to volume imaging, at least in principle. Advantages include potential improvement in *signal-to-noise ratio* by including signal from the whole volume at once; disadvantages include a bigger computational task for image reconstruction and longer *image acquisition times* (although the entire volume can be imaged from the one set of data). Also called simultaneous volume imaging or three-dimensional Fourier transform (3DFT) imaging.

**Volume-selective excitation**. Selective excitation of spins in only a limited region of space. This can be particularly useful for spectroscopy as well as imaging, as spatial localization of the signal source may be achieved through spatially *selective excitation* and the resulting signal may be analyzed directly for the spectrum corresponding to the excited region. It is usually achieved with selective excitation. Typically, a single dimension of localization can be achieved with one selective RF excitation pulse (and a magnetic field gradient along a desired direction), while a localized volume (3-D) can be excited with a *stimulated echo* produced with three selective *RF pulses* whose selective *magnetic field gradients* are mutually orthogonal, having a common intersection in the desired region. Similar "crossed plane" excitation can be used with selective 180° refocussing pulses and conventional spin echoes. A degree of spatial localization of excitation can alternatively be achieved with *depth pulses*, e.g., when using surface coils for excitation as well as signal detection. An indirect application of selective excitation for volume-selected spectroscopy is to use appropriate combinations of signals acquired after selective *inversion* of different regions, in order to subtract away the signal from undesired regions.

**Voxel**. Volume element; the element of 3-D space corresponding to a *pixel*, for a given slice thickness.

# W

**Wash-in effects**. See *flow-related enhancement*.

**Wash-out effects**. See *flow void.*

**Water-suppression**. The elimination or reduction of water signal from the image by application of a narrow-band frequency-selective pulse centered around the *resonant frequency* of the tissue.

# X–Z

**x**. Dimension in the stationary (laboratory) frame of reference in the plane orthogonal (at right angles) to the direction of the static *magnetic field* ($B_o$ *or* $H_o$), *z*, and orthogonal to *y*, the other dimension in this plane. This is commonly defined to be in the direction of the *frequency-encoding gradient.*

**x'**. Dimension in the *rotating frame of reference* in the plane at right angles to the direction of the *static magnetic field* ($B_o$ *or* $H_o$), *z*; commonly defined to be in the direction of the magnetic vector of the *exciting RF* field ($B_1$).

**y**. Dimension in the stationary (laboratory) frame of reference in the plane orthogonal to the direction of the static *magnetic field* ($B_o$ *and* $H_o$), *z*, and orthogonal to *x*, the other dimension in this plane. This is commonly defined to be in the direction of the *phase-encoding gradient.*

**y'**. Dimension in the *rotating frame of reference* in the plane orthogonal (at right angles) to the direction of the static *magnetic field* ($B_o$ *and* $H_o$), *z*, and orthogonal to the other dimension in the plane, *x'*.

**Yoke**. High *permeability* structure used to concentrate the magnetic flux inside itself and thus decrease the *magnetic fringe field* and increase the field strength in the useful volume of a magnet.

**z**. Dimension in the direction of the static *magnetic field* ($B_o$ *and* $H_o$), in both the stationary and *rotating frames of reference*.

**Zero filling**. Substitution of zeroes for unmeasured data points in order to increase the matrix size of the new data prior to *Fourier transformation* of *MR* data. This can be equivalent to performing an interpolation in the transformed data, resulting in *pixels* smaller than the actual *resolution* of the image.

**Zeugmatography**. Term for *MR imaging* coined from Greek roots suggesting the role of the *magnetic field gradient* in joining the *RF* magnetic field to a desired local spatial region through *magnetic resonance*.

# Symbols and Abbreviations

**2DFT**. See *Two-dimensional Fourier transform.*

$\gamma$. See *Gyromagnetic ratio.*

$\delta$. See *Chemical shift.*

$\mu$. See *Permeability.*

$\tau$. Often used to denote different time delays between RF pulses. See *Interpulse times.*

$\chi$. See *Magnetic susceptibility.*

$\omega$. See *Angular frequency.*

$\omega_{\mathbf{o}}$. See *Larmor frequency.*

## Basic Quantities in Electricity and Magnetism

A generally complete understanding of the basic facts of electricity and magnetism has been available for about a century. During that time several sets of mathematical and physical quantities have been used to represent the concepts required for various applications. Some confusion has arisen from the resultant proliferation of quantities and units. The International System of Units – abbreviated SI – is being used as an attempt to improve communications among workers in various fields.

The modern theory of electricity and magnetism is based on a group of four interrelated formulas known as the Maxwell equations. These formulas describe the way in which charges produce electric fields and how charges in motion – that is, electric currents – produce magnetic fields. They also show that magnetic fields that vary with time produce electric fields and vice-versa. The basic quantities of the Maxwell equations are a magnetic field B (formally called the magnetic induction or magnetic flux density) and an electric field E. These are vector fields – that is they have both a magnitude and a direction which change from point to point in space. Ultimately the fields B and E are defined and measured in terms of forces that they exert on bodies that are charged or that carry electric currents.

Vector fields are most conveniently described in terms of their components that give the strength of the field in each of the three perpendicular directions. For example, the magnetic field vector **B** has components $B_x$, $B_y$, and $B_z$ along the Cartesian coordinates x, y, and z. By convention, in MR, the direction z is taken as the direction of the main magnetic field, $\mathbf{B_o}$ , and x and y are perpendicular to this field.

Only a few of the many quantities used in electromagnetic theory are required to understand the principles of MR. However, several others are sometimes used for specialized purposes. For this reason both the commonly used quantities and some of the less commonly used ones are described in the accompanying table. Although these definitions are technically accurate, they are not intended to be formally rigorous.