Physics of NMR

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The nuclear magnetic resonance phenomenon can be summarized as follows. If we place a suitable sample in a static magnetic field and, after waiting a sufficient time, we irradiate it with a radiofrequency (RF) magnetic field pulse (energy) at the appropriate frequency, the nuclei in the sample will show at least one energy absorption peak. The frequency of the radiation necessary for absorption depends on three conditions: (i) on the type of nucleus (e.g., 1H, 13C, 31P, 23Na, etc); (ii) on the chemical environment of the nucleus (e.g. the methyl and hydroxyl protons of methanol absorb at different frequencies); and (iii) on the local intensity of the static magnetic field. This last variable provides the basis for magnetic resonance imaging (MRI), for self-diffusion coefficient measurements, and for coherence selection. For diffusion coefficient measurements and MRI, the magnetic field variation is linear over the sample. However, for most spectroscopic purposes the magnetic field needs to be as homogeneous as possible over the sample (variation less than 10 ppb over the whole volume). After absorption of energy by the nuclei, the length of time and the way in which the nuclei dissipate that energy can also be used to reveal information regarding the microscopic structure of the sample and also a variety of dynamic processes.
This introductory lecture will cover the following basic NMR concepts: angular momentum and magnetic moments of nuclear spins; spins in a homogeneous magnetic field; the resonance phenomenon; magnetization; equilibrium population distribution and the Boltzmann equation; the Bloch equations; Larmor precession; rotating frame; transition mechanisms; longitudinal (T1) and transverse (T2) relaxation times; continuous-wave (CW) NMR; steady state NMR experiments and saturation; pulsed NMR techniques; the effect of a single RF pulse; free induction decay; the effect of multiple RF pulses; inversion recovery; spin echo; gradient echo; Fourier-Transform NMR; pulse methods for T1, T2 and T2* measurement; general features of the NMR spectrum; linewidth; peak intensity; chemical shift; spin-spin coupling; nuclear spin in magnetic field gradients; frequency encoding; selective excitation.