ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
Department of Physics

Nuclear Magnetic Resonance (NMR)

Abstract

Nuclear magnetic resonance (NMR) spectroscopy deals with the *interaction of electromagnetic radiation with magnetic moments of nuclei*. Due to their coupling with electrons, nuclei are highly-sensitive local probes, able to deliver both static and dynamic information on a wide variety of systems. Today NMR is widely applied in chemistry, biology, medicine, physics, etc.

Objectives:

- Learn the basics of radio-frequency spectroscopy.
- Understand pulsed FT NMR and MR imaging.
- By means of simple NMR measurements, detect ^{1}H NMR signals, measure relaxation rates, and reconstruct the images of 3D objects.

Felix Bloch and Edward Purcell, discoverers of NMR and Nobel Prize in Physics in 1952.

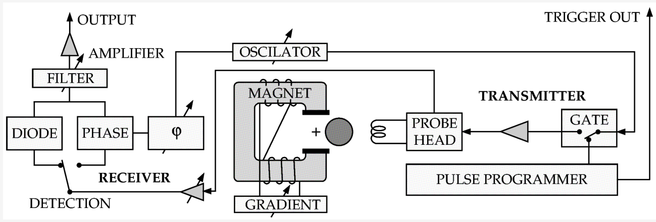

Fig. 2: Simplified block diagram of the NMR spectrometer. The gate allows the generation of complex RF pulse sequences. The additional coils create a field gradient, thus enabling magnetic resonance imaging (MRI).

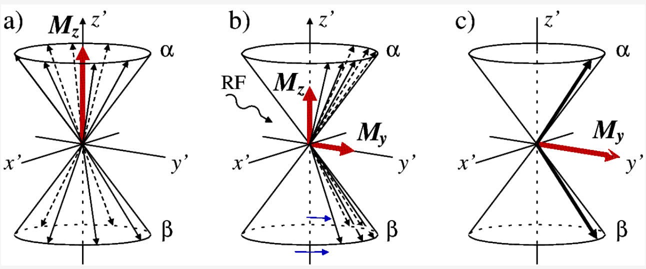

Fig. 1: Excitation of magnetization in the rotating reference frame. (a) The thermal equilibrium distribution of individual nuclear spins creates a macroscopic magnetization $\boldsymbol{M_z}$. (b) The absorption of radio-frequency (RF) generates a *microscopic phase coherence* among the individual spins, equivalent to the rotation of the net magnetization towards *y'*. (c) For a suitably calibrated RF pulse the ensemble of spins acquires maximum phase coherence.

Experimental approach

To detect the nuclear magnetic resonance signal of protons, a water ampule (circle in Fig. 2) is positioned in a magnetic field. Irradiation by RF pulses modifies the thermodynamic equilibrium of nuclei, which are then left to precess freely and produce a time-domain NMR signal. Its successive Fourier transform (FT) gives the NMR spectrum (line shape), whose details depend on the electronic environment of the nuclei. By means of RF pulse sequences one can investigate the return of the nuclei to equilibrium, determine their relaxation rates, and thus measure, e. g., water purity.
In additional experiments, the joint use of RF pulses and magnetic-field gradients is used to determine the coefficient of self-diffusion of water, or to acquire cross sections of complex-shaped objects (tomography).

Results

The NMR signal and line-shape of protons in water in a 0.21-T applied field are shown in Figs. 3a-b. More complex NMR lines are observed in solids. By using magnetic-field gradients, one can carry out magnetic resonance imaging (MRI) and obtain the cross section of inhomogeneous objects (Fig. 3c).

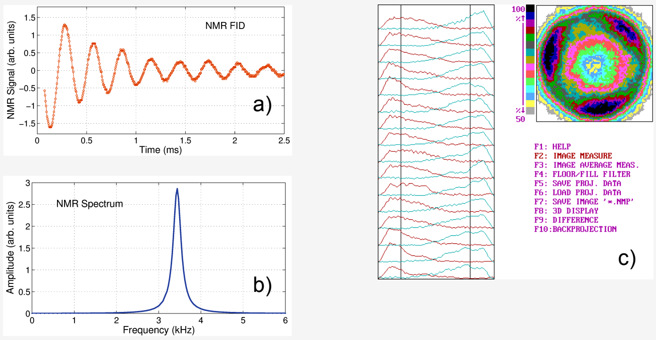

Fig. 3: Time-domain proton-NMR signal (a) and its line-shape, as obtained via Fourier transform (b). Cross section of a 3D object, obtained by combining the NMR ^{1}H spectra collected in an applied magnetic field gradient (c).

Further Reading

- M. H. Levitt, *Spin Dynamics,* 2nd ed. (Wiley, Chichester, 2008).
- J. Keeler, *Understanding NMR*, 2nd ed. (Wiley, Chichester, 2010).
- D. Traficante, *NMR Concepts*, in M. D. Bruch ed., *NMR Spectroscopy Techniques*, 2nd ed., Vol. 21 (Marcel Dekker, NY, 1996).
- G. Schatz, A. Weidinger, M. Deicher, *Nukleare Festkörperphysik,* 4. Aufl. (Vieweg + Teubner, Wiesbaden, 2010), Kap. 6.