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Ewa Kmiecik

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Magnetic resonance sounding technique

author(s): **Sunjay Sunjay**
BHU, Department of Geophysics, India, `sunjay.sunjay@gmail.com`

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The Magnetic Resonance Sounding (MRS) technique is a sounding (i.e. depth discriminating) surface geophysical method. In contrast to most other geophysical techniques, the MRS technique is based on two nuclear constants: the $^1H^+$ gyromagnetic ratio (γ), which provides MRS with its selectivity for water, and the nuclear magnetisation of the water molecule, M_0, which provides MRS with its absolute quantification of water content. The NMR signal is dependent not only on the in-situ groundwater content and its depth, but also on the strength of the earth's spatially dependent magnetic field, whereas the noise is related to lightning and/or artificial man-made noise sources i.e. electrical power lines etc. The evaluation of the potential use of MRS in direct detection of groundwater contamination and in tracer imaging, based on the literature study of NMR hydrocarbon detection and tracer imaging in laboratory conditions indicates that the MRS technique similar to NMR applications, is restricted to the substances containing hydrogen and that the implications of the field scale of the MRS experiment and heterogeneity involved make it additionally challenging. The main advantage of MRS as compared to other classical geophysical methods is that it is water selective, which means that an excitation is at the specific hydrogen nuclei resonance precession frequency so the response is unique for water (e.g. groundwater). The most important limitations are related to MRS investigations in electrically conductive environments, in environments with low S/N (Signal to Noise) ratio and in areas with inhomogeneous magnetic field. In electrically conductive environments, an inversion is distorted by attenuation of a signal by conductive layers. The main advantage of the MRS method as compared to other geophysical methods is in its water selectivity. MRS detects free water content, which combines retained water and gravitational water. Currently with MRS it is not possible to differentiate these two water types. Field experiments indicate that MRS is not appropriate for groundwater salinity detection. Applications of MRS: Aquifer parameterization, Water content interpretation, Hydraulic conductivity and transmissivity by decay time constant , Volumetric data integration**,** Well siting, Water in unsaturated zone and groundwater recharge, Aquifer geometry: MRS provides free water content and an estimate of permeability with depth. Therefore it can be used for evaluation of the aquifer geometry i.e. the detection of unconfined groundwater table depth and layer boundaries (tops and bottoms) both called hydrostratigraphic boundaries and in the future for evaluation of various 2D and 3D hydrogeological features.

NMR Principle: The MRS technique is a specific application of NMR to groundwater investigations conducted from the Earth's surface. In nuclear magnetic resonance (NMR), nuclear refers to the fact that the phenomenon occurs at the nucleus level of atoms (major constituents of nuclei are neutrons and protons). Magnetic refers to a field similar to the Earth's magnetic field, except that the NMR magnetic field originates from the nuclei rather than the electrons. Resonance refers to the excitation/detection mode, which occurs at specific Larmor frequency. NMR can be observed only on specific isotopes of some elements, e.g. hydrogen, carbon, phosphorus, etc., with a net nuclear angular momentum and a magnetic quantum number. Such a nucleus has a weak nuclear magnetic moment (similar to a tiny magnet), which, at steady state and on average, is aligned with the local (static) magnetic field. It has also a weak spin angular momentum. If such averaged magnetic moment is put into any other orientation by a momentary external excitation, it will precess around the local magnetic field orientation at the Larmor precession frequency, in a way very similar to the precession of a spinning top when its axis is misaligned with respect to the gravity field. The hydrogen (1H) nucleus is made of a single proton, and hydrogen nuclei ($^1H^+$) occur as one of the major constituents of the water molecule. The excitation field (B_{exc}) is used to displace the average nuclear magnetic moment from the direction of the ambient magnetic field. This excitation is usually done by energizing the volume to be investigated with an alternating (AC) magnetic field oscillating at the Larmor frequency (resonance) and oriented perpendicular to the ambient (static) magnetic field. Each isotope with a spin has a specific gyromagnetic ratio γ (with $\gamma=\mu/Lp$). For hydrogen, m is the $^1H^+$ magnetic moment (1.4×10^{-26} J/T) and L_p is its spin angular momentum (5.3×10^{-35} J s). The Larmor frequency f_l (in Hz) is (Slichter, 1996) $f_l=\gamma.B/2\pi$ where B is the static magnetic field (in T). During an NMR measurement, which is performed at a specific Larmor frequency, only nuclei with a γ corresponding to the excitation frequency are precessing. After the excitation, the precessing nuclei will return to their steady state orientation at a rate determined by various ‘relaxation factors’. Important developments have also been made in the field of hydrocarbon resources exploration and quantification through advances in petrophysics and in NMR borehole logging tools, which provide direct determination of porosity, pore-size distribution and pore fluid content. In all these NMR applications, the applied static magnetic field is much larger than the Earth’s magnetic field because the nuclear magnetic moment is very small and the resulting NMR signal is also very small, but proportional to the square of the static magnetic field (B^2). In practice, therefore, NMR instrument designers include the highest performance (electro)magnet in their NMR systems.

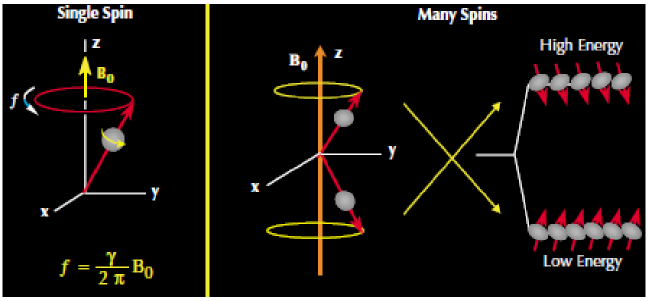

Figure 1. In an external magnetic field (left), the precessional frequency of a nucleus depends on the gyromagnetic ratio of the nucleus and the strength of the external field. The alignment of the precessional axis of the nucleus with respect to the direction of the external field (right) determines the energy state of the nucleus.

WT a useful microscope to study signals in many areas. In spectrum data processing, WT can be used in noise-data filtering, data compressing, baseline correction, peaks detection and discrimination. characteristics of Nuclear Magnetic Resonance (NMR) spectrum, how to process NMR spectrum with WT, and advantage of adopting WT to filter noise data and detect the peaks in NMR spectrum processing. Resolution of the NMR Spectrum Using Wavelet Transform: For resolution of an overlapping nuclear magnetic resonance (NMR) spectrum using the wavelet transform (WT) is applied. An NMR spectrum can be decomposed in a series of localized contributions(details & approximations) at different resolution levels, which represent the spectral information at different resolution. With the amplification of the contributions of fine resolution level and then reconstruction (inverse transform), the resolution of reconstructed NMR spectrum will increase. Therefore the resolved spectrum can be obtained from a low resolution spectrum or an overlapping spectrum. Wavelet analysis is employed for geophysical well logging signals due to its nonstatinary character. Method: Jean P Morlet (French geophysicist pioneer) first generation wavelet analysis-High resolution; Second generation wavelet transform

(SGWT)/lifting scheme –super resolution; third generation wavelet a Complex Finite Ridgelet Transform (CFRIT), to achieve the forensic dissection, morphological features from micro/nano scalar of surface topographic data. Complex Wavelet Transform is used to rectify & pacify limitations; shift sensitivity, poor directionality, and absence of phase information.

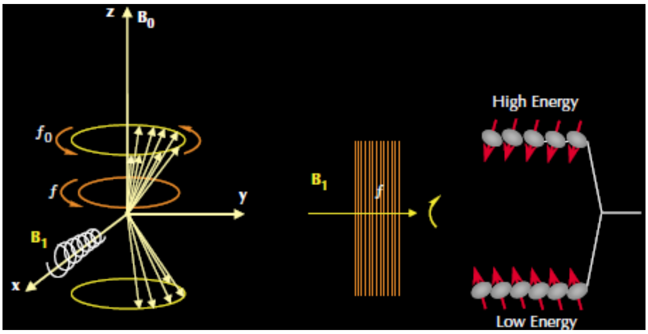

Figure 2. For effective interaction with protons (left), the oscillating magnetic field must have a substantial component perpendicular to the static field B_0 and must have frequency f equal to the proton's Larmor frequency f_l in the static field. In this case (right), the protons will precess in phase with one another and may absorb energy from the oscillating field and change to the high-energy state. Nuclear magnetic resonance thus occurs.

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