# Medical Image Processing for Diagnostic Applications

## MRI – Physical Background

Online Course – Unit 20

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# Topics

On the Physics of MRI

Pros and Cons of MRI

Summary

- Take Home Messages
- Further Readings

# Nuclear Magnetic Moments

Wolfgang Pauli (1900–1958) found out that, besides mass and charge, particles have another fundamental property, the so-called **spin**:

- The spin angular momentum is denoted by $\boldsymbol{J} \in \mathbb{R}^3$.
- A nuclear spin is associated with a microscopic magnetic field, because nuclei, like protons, carry electrical charges and rotate around their own axes if the spin is nonzero.
- The nuclear magnetic moment (or dipole moment) is denoted by $\boldsymbol{\mu} \in \mathbb{R}^3$.
- The spin angular momentum and the magnetic moment are collinear, i. e.,

$$\boldsymbol{\mu} = \gamma \cdot \boldsymbol{J}$$

where $\gamma$ is the nucleus dependent gyromagnetic ratio.

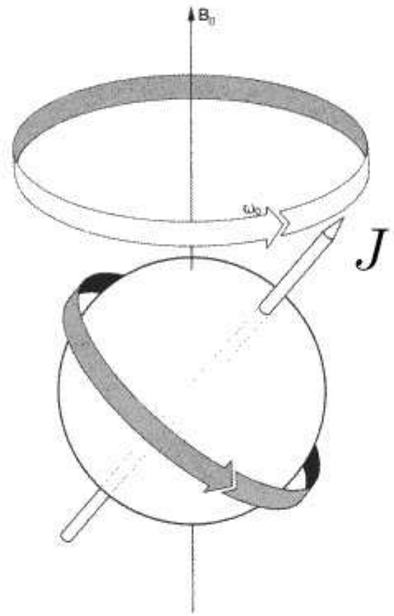


Figure 1: Scheme of the nuclear spin

# Nuclear Magnetic Moments

- From the theory of quantum mechanics we know that the magnitude of the magnetic moment is given by

$$||\boldsymbol{\mu}|| = \gamma \frac{\hbar}{2\pi} \sqrt{I(I+1)},$$

  where
  - $\hbar = 6.626\,068 \times 10^{-34}\,\mathrm{m^2 kg/s}$ is Planck's constant, and
  - $I = 0, \pm\frac{1}{2}, \pm 1, \pm\frac{3}{2}, \ldots$ is the spin quantum number.
- To achieve macroscopic magnetism it is required to line up spin vectors, and this can be enforced by a strong external magnetic field $\boldsymbol{B}_0$.
- The precession frequency $\omega_0$ of $\boldsymbol{\mu}$ given by the Larmor equation $B_0 = ||\boldsymbol{B}_0||$ is

$$\omega_0 = \gamma B_0.$$

  The frequency $\omega_0$ is called Larmor frequency.

# Intensities in MRI

Intensities in MR images depend on:

- spin density,
- spin-lattice relaxation time (T1),
- spin-spin relaxation time (T2),
- molecular motion (diffusion, perfusion, flow).

# MR Image Acquisition

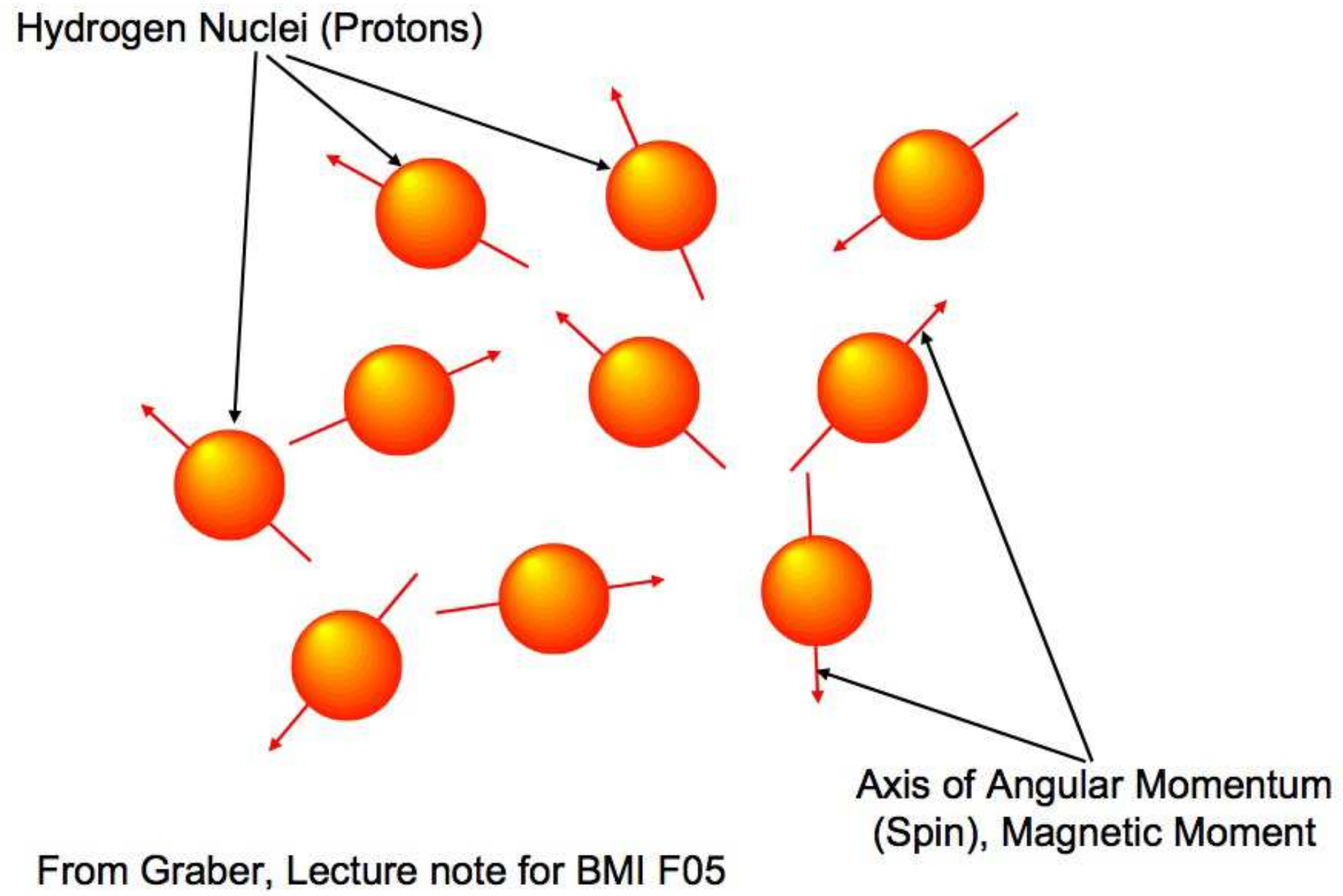


Figure 2: Naturally random spin orientation of nuclei

# MR Image Acquisition

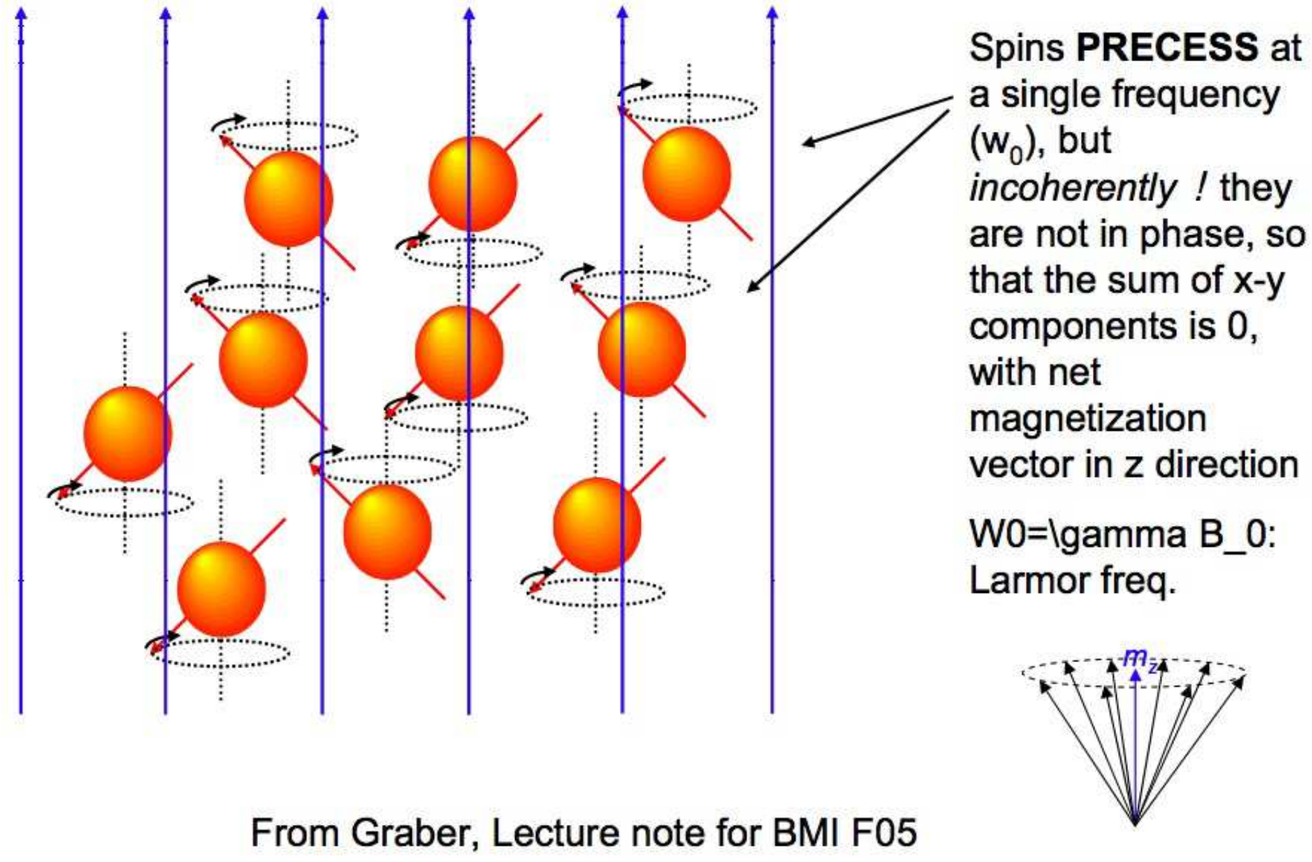


Figure 3: Spin alignment with static magnetic field

# MR Image Acquisition

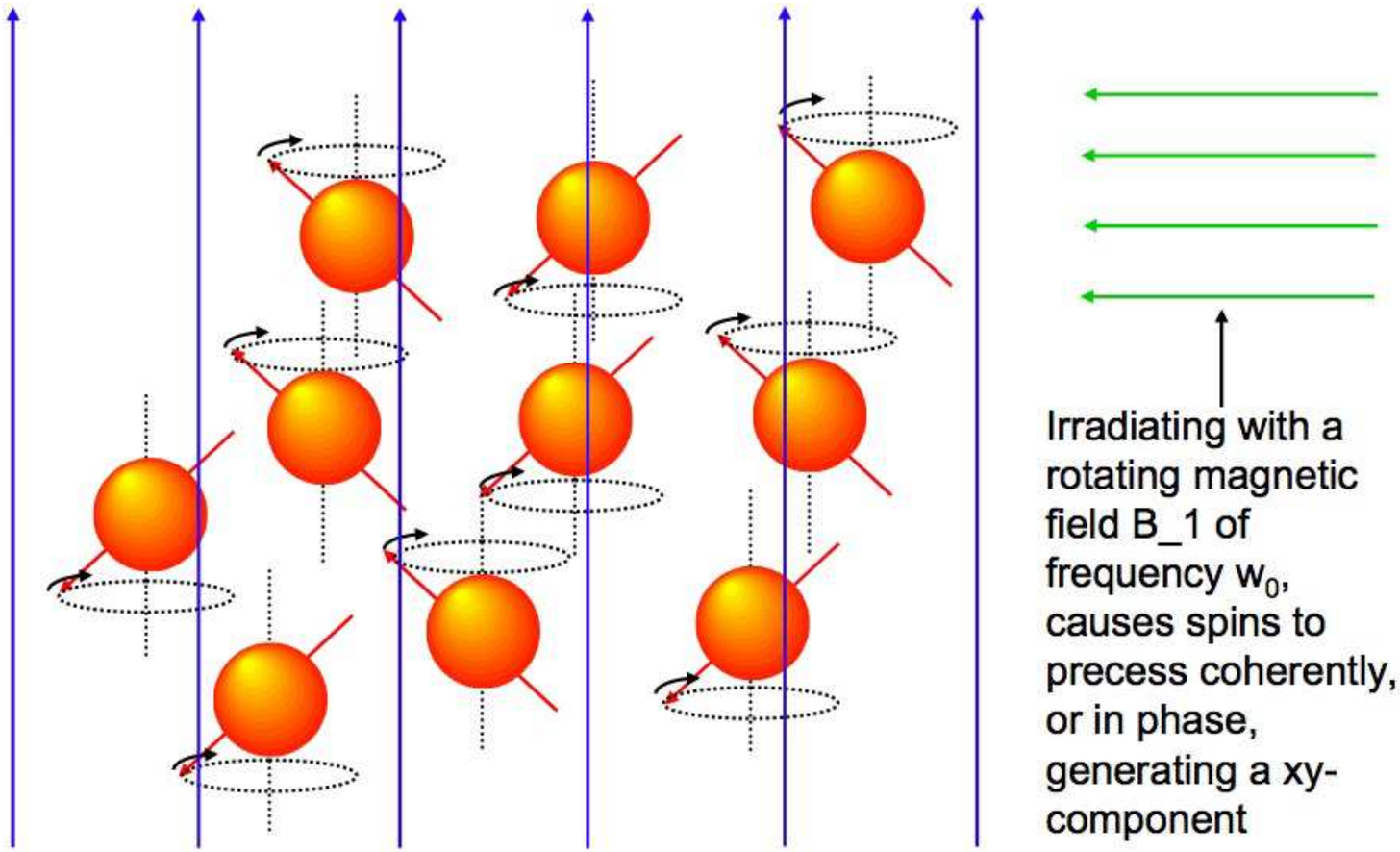


Figure 4: Excitation with rotating magnetic field

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# Pros and Cons of MRI

## Selected Pros

- Patient care (radio frequencies from $10^6$ Hz to $10^8$ Hz, and wavelengths from 1 Hz to 100 Hz, no X-ray!)
- High spatial resolution (50 µm and lower)
- Excellent contrast resolution (discrimination of soft tissues)
- Rich information about anatomical structure
- Anatomical reference for functional modalities
- Enables quantitative studies
- Pre-, intraoperative guidance for intervention
- Functional imaging modality (diffusion, perfusion, flow imaging)
- Enables the usage of contrast agents

# Pros and Cons of MRI

**Selected Cons**

- Magnetic field makes devices and especially hybrid scanners expensive (investment and maintenance).
- Inhomogeneities are caused by the radio frequency coil.
- Intensity inhomogeneities produce spatial changes in tissue statistics.
- Intensity-based segmentation fails due to inter- and intra-scan inhomogeneities.
- Inhomogeneities can change with different acquisition parameters, from patient to patient, and from slice to slice.
- It is dangerous to approach the magnet with ferro magnetic objects, see for instance here.

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# Take Home Messages

- MRI physics are based on the magnetic spin orientation of the nuclei in a strong static magnetic field. Deflecting the spins with a second magnetic field enables the readout for all axes.
- There are a lot of advantages of this technology, but also some disadvantages. Intensity inhomogeneities are a major issue which is adressed in the next units.

# Further Readings

The webpage of the National High Magnetic Field Laboratory can be one starting point for more detailed information regarding MRI. For an initial overview of the technology, the following article is worth reading:

MRI: A Guided Tour by Kristen Coyne.

Another article worth reading is this survey paper on algorithms for intensity correction methods:

Zujun Hou. “A Review on MR Image Intensity Inhomogeneity Correction”. In: *International Journal of Biomedical Imaging* 2006.Article ID 49515 (Feb. 2006), pp. 1–11. DOI: 10.1155/IJBI/2006/49515