Medical Image Processing for Diagnostic Applications

Modalities – Magnetic Resonance Imaging - Part 1

Online Course – Unit 53

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Topics

Magnetic Resonance Imaging (MRI) ...

- ... used to be called “Nuclear Magnetic Resonance Imaging” (NMRI).
- ... measures the distribution of hydrogen atoms:

$\rightarrow$ it yields very good soft tissue contrast,

$\rightarrow$ and it yields low contrast for other materials such as bone or air.

Figure 1: Brain MRI (Zeng, 2009)

Magnetic Resonance Imaging: Proton Spin

Spinning protons act like tiny magnets:

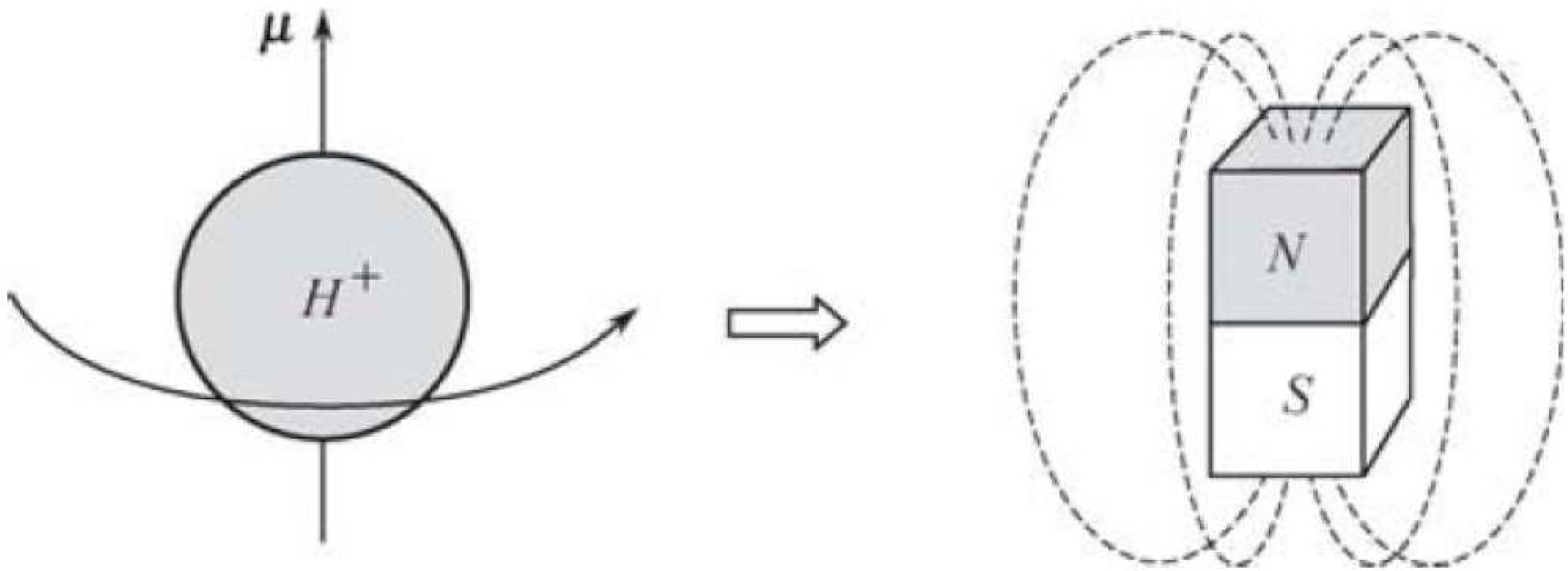

Figure 2: Illustration of the proton spin (Zeng, 2009)

Magnetic Resonance Imaging: Proton Spin

As the protons are oriented in random directions the net magnetic moment is zero:

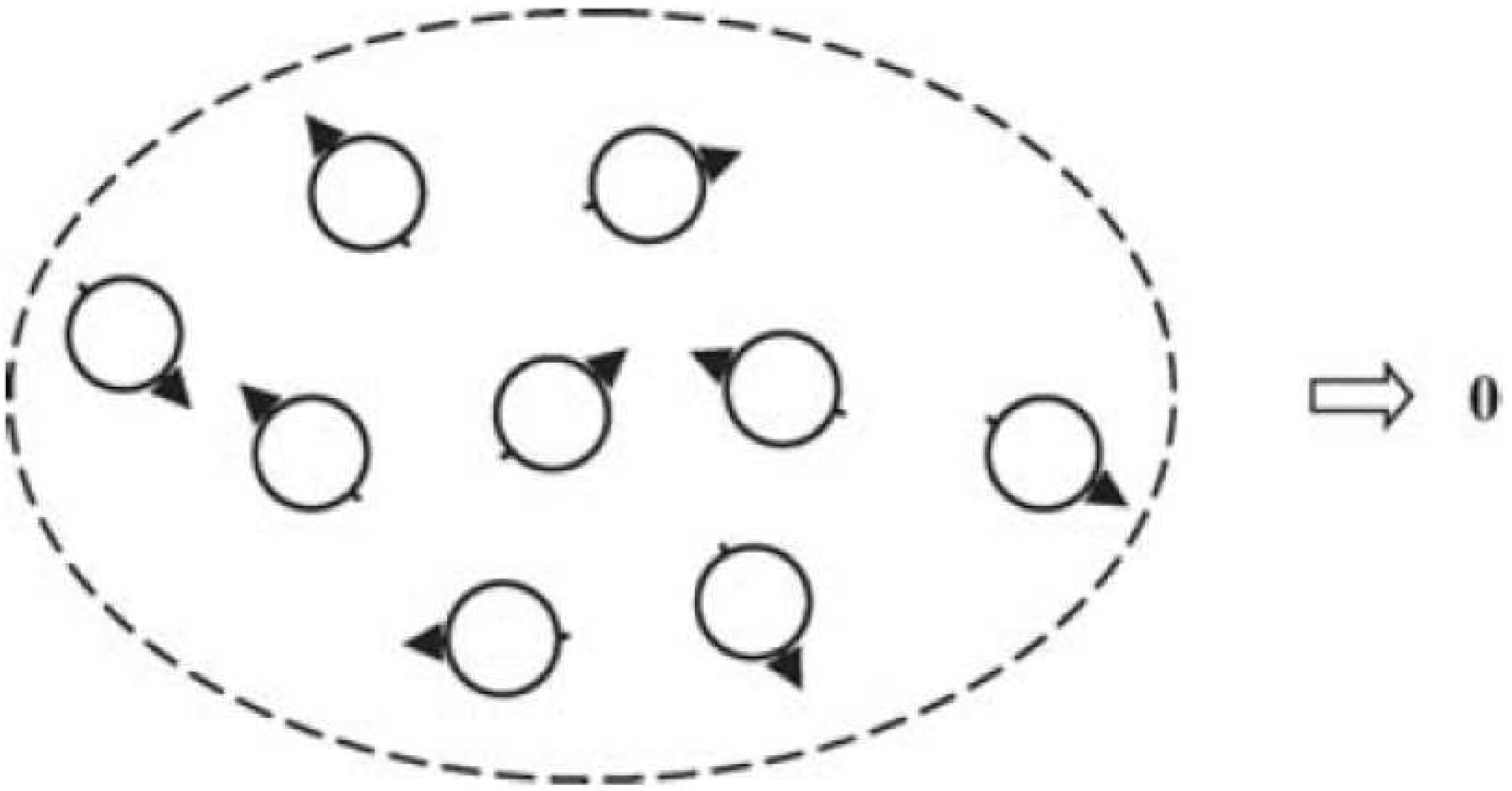

Figure 3: Spins are equalized without external interaction (Zeng, 2009).

Magnetic Resonance Imaging: Spin Orientation

- If an external magnetic field is applied, the protons orient along this field.
- About half of them point towards the south pole of the field, while the others point towards the north pole.
- Due to this imbalance, a small magnetic moment is created.
- The magnitude M of the net magnetic moment $\boldsymbol{M}$ is proportional to

$$M \sim \frac{\gamma \hbar B_0}{2 k_B T}.$$

T is the temperature (in K),
$k_B \approx 8.617 \times 10^{-5}\,\mathrm{eV\,K^{-1}}$ is the Boltzmann constant,
$\hbar \approx 1.055 \times 10^{-34}\,\mathrm{J\,s}$ is the reduced Planck constant,
γ is the atom-dependent gyromagnetic ratio
(e. g., $42.58\,\mathrm{MHz\,T^{-1}}$ for hydrogen nuclei),

B_0 is the strength of the external magnetic field.

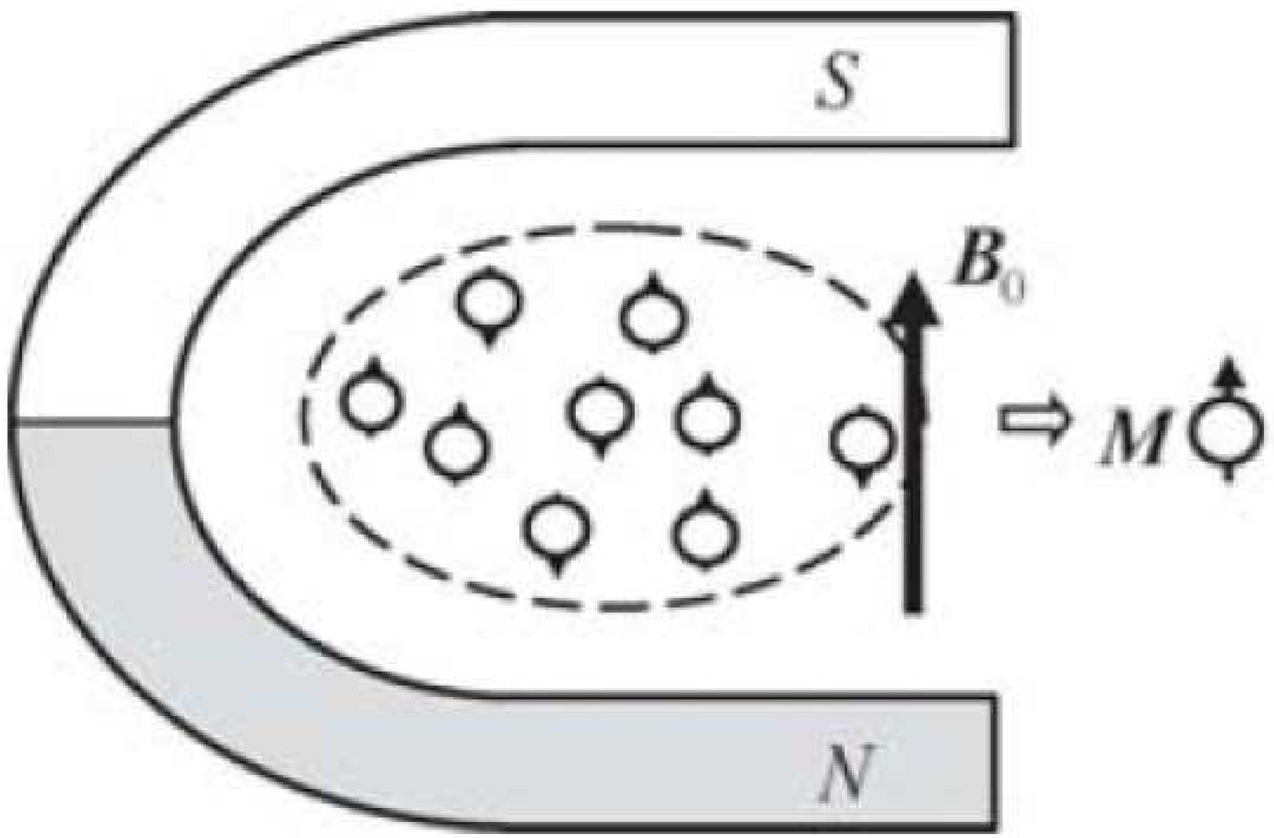

Figure 4: There is a magnetic field due to two different spin types (Zeng, 2009).

Magnetic Resonance Imaging: Precession

- Each of the hydrogen atoms is spinning.
- If the spin axis is not along the external magnetic field axis, **precession** happens.

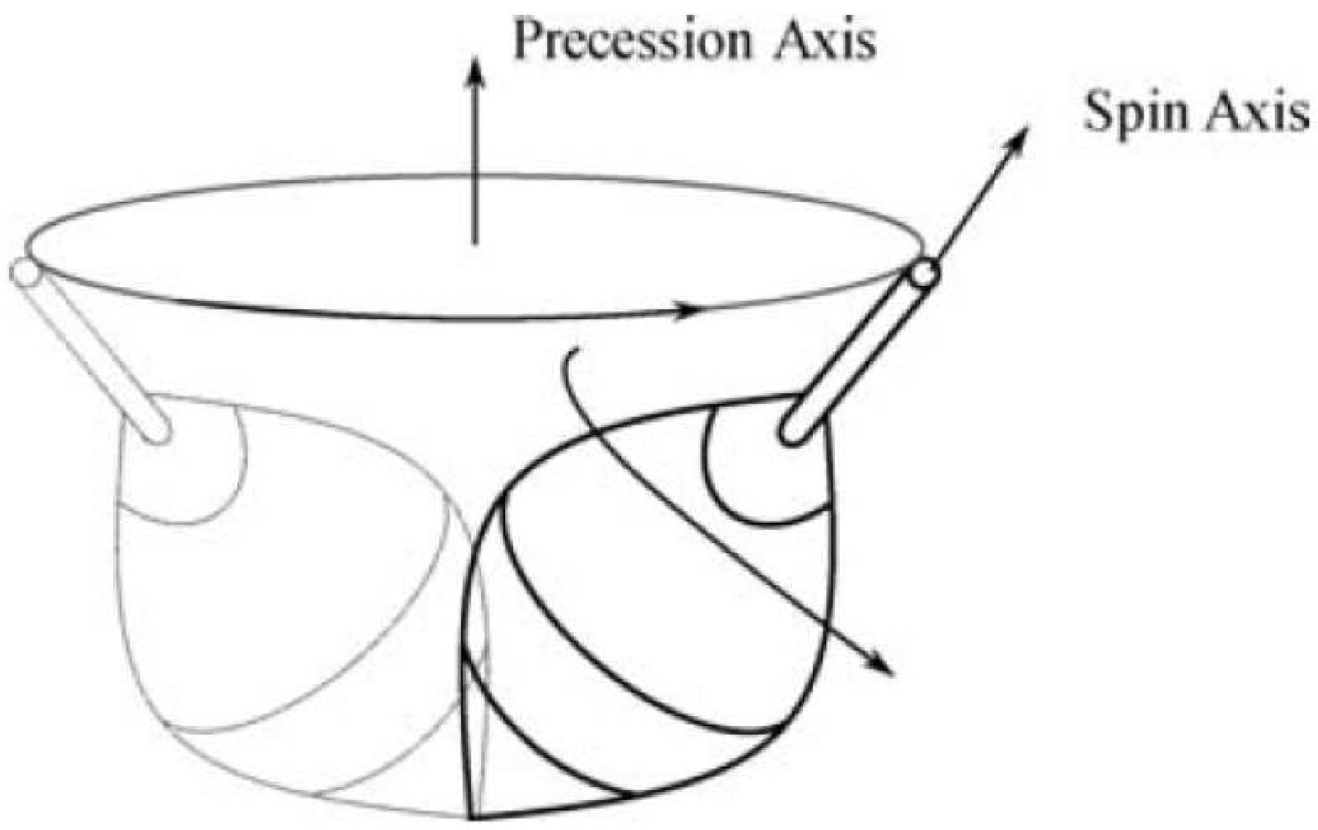

Figure 5: Illustration of precession (Zeng, 2009)

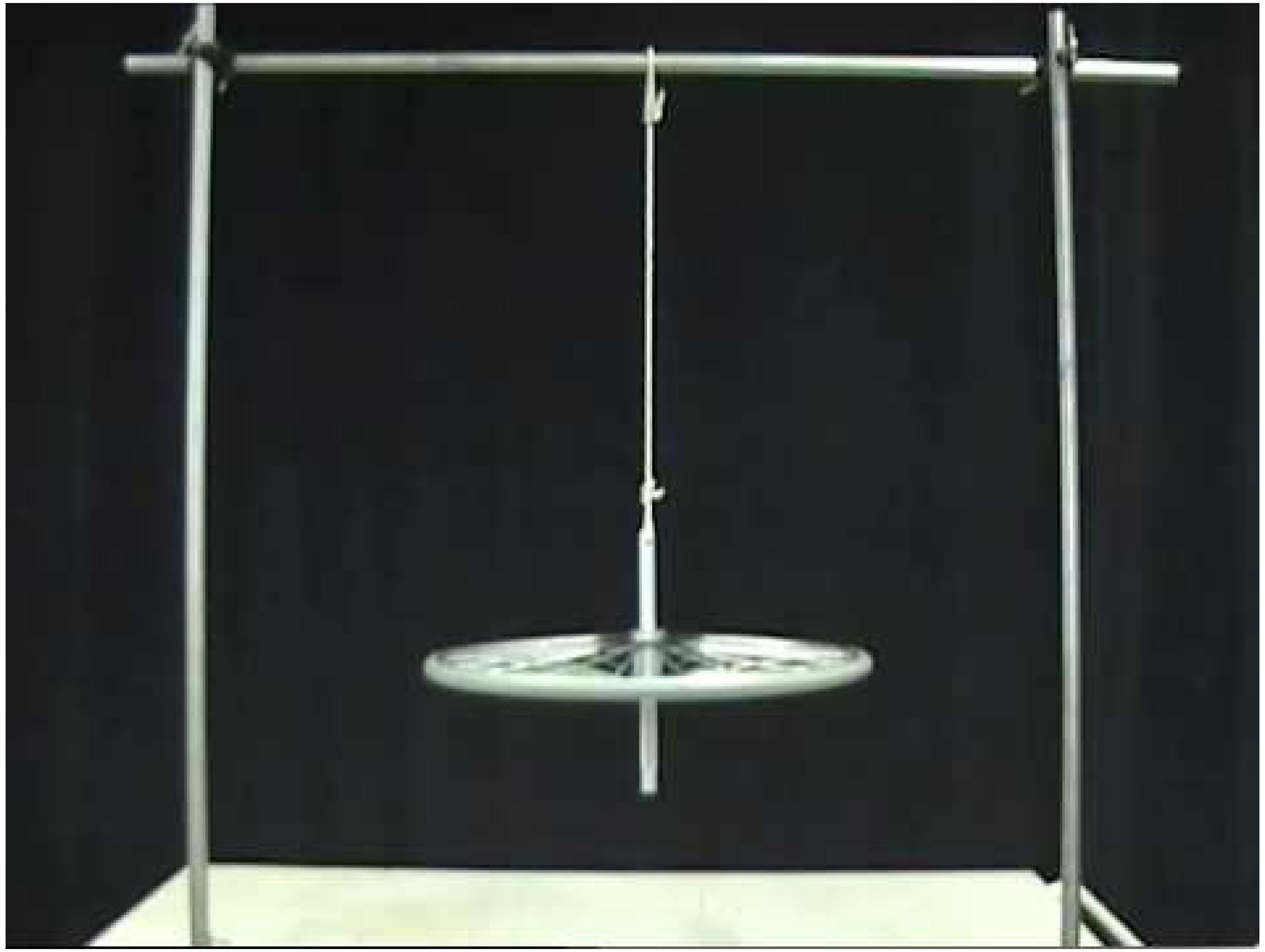

Figure 6: Bicycle wheel gyroscope, MIT Physics Demo, link: `http://www.youtube.com/watch?v=8H98BgRzpOM`

Magnetic Resonance Imaging: Precession

If the atom is “knocked off balance”, afterwards it returns to its equilibrium position:

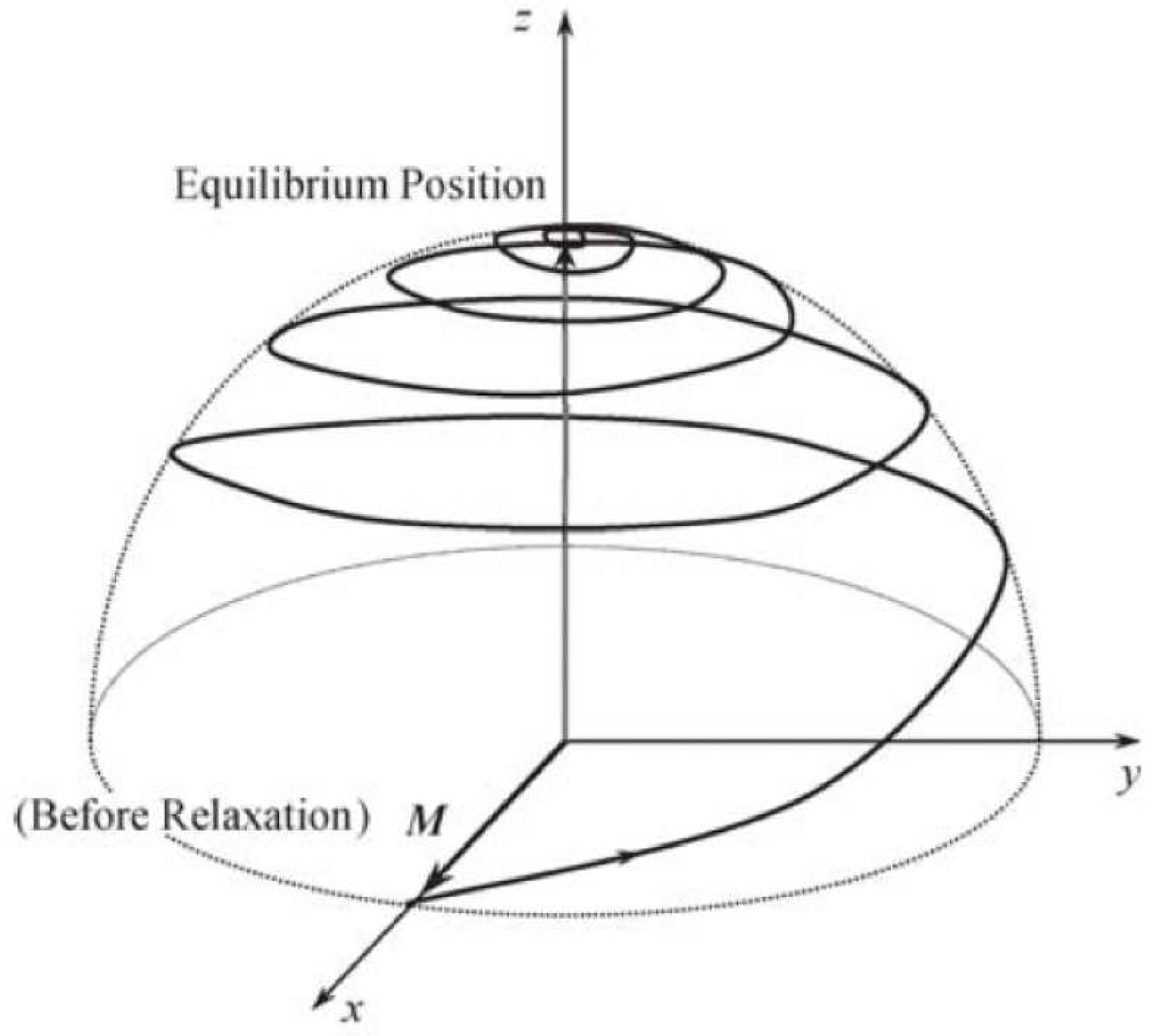

Figure 7: Excitated protons align with the magnetic field with precession (Zeng, 2009).

Magnetic Resonance Imaging: Precession

- The precession of Hydrogen protons is at the Larmor frequency

$$\omega_0 = \gamma B_0,$$

  where γ is the atom-dependent gyromagnetic ratio ($42.58\,\mathrm{MHz\,T^{-1}}$ for hydrogen), and B_0 is the strength of the external magnetic field.
- This frequency is in the range of FM radio ($\sim 64\,\mathrm{MHz}$ at $1.5\,\mathrm{T}$).

Magnetic Resonance Imaging: Frame of Reference

- Consider a second coordinate system that rotates at the Larmor frequency.
- In this coordinate system, there is no precession.

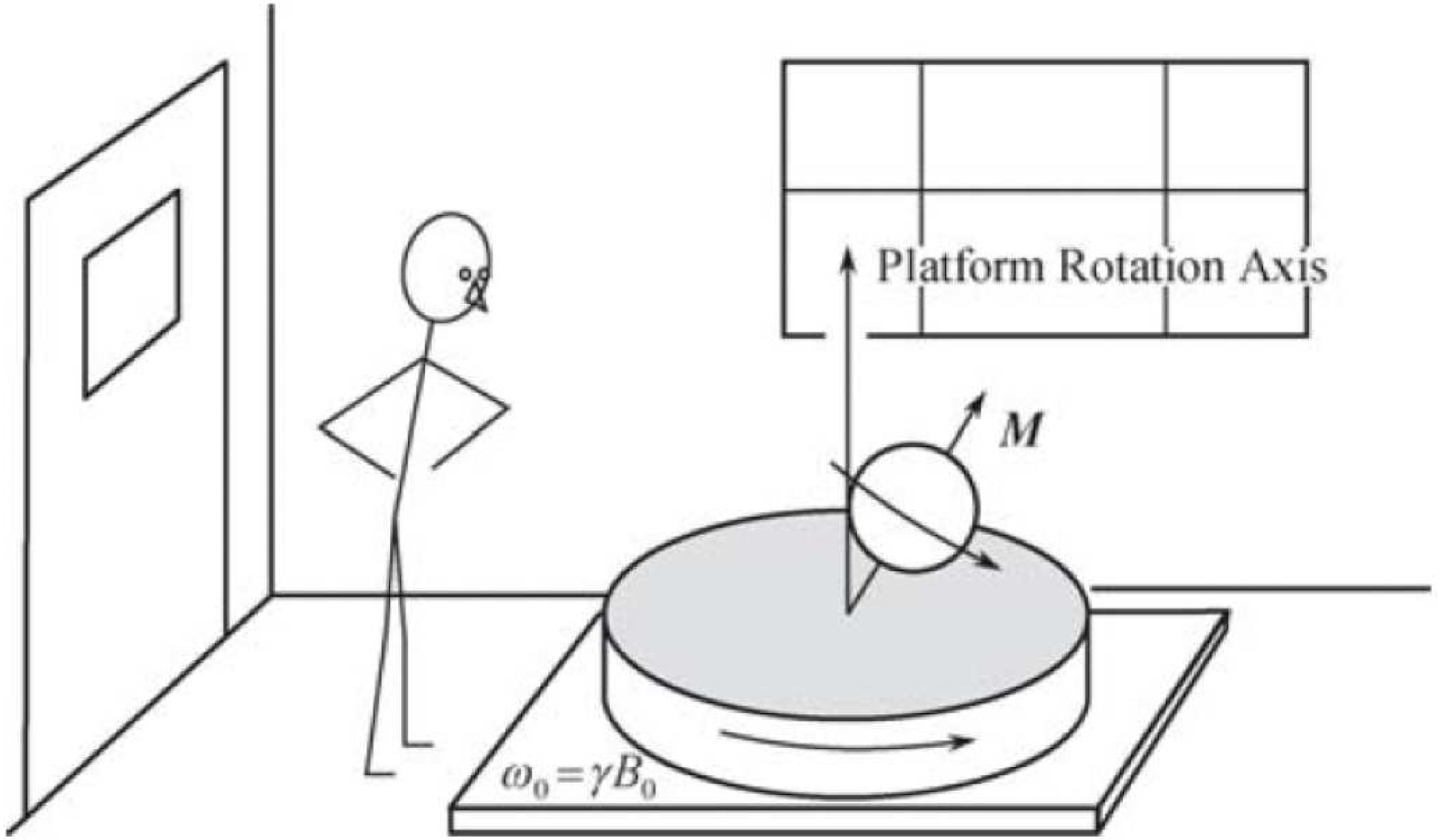

Figure 8: Initial coordinate system (Zeng, 2009)

Magnetic Resonance Imaging: Frame of Reference

- In this new coordinate system, we can apply another field $\boldsymbol{B}_1$ to knock the spin axis off balance.
- After excitation, the field can be turned off again.

$\rightarrow$ The spin axis will return to its equilibrium position.

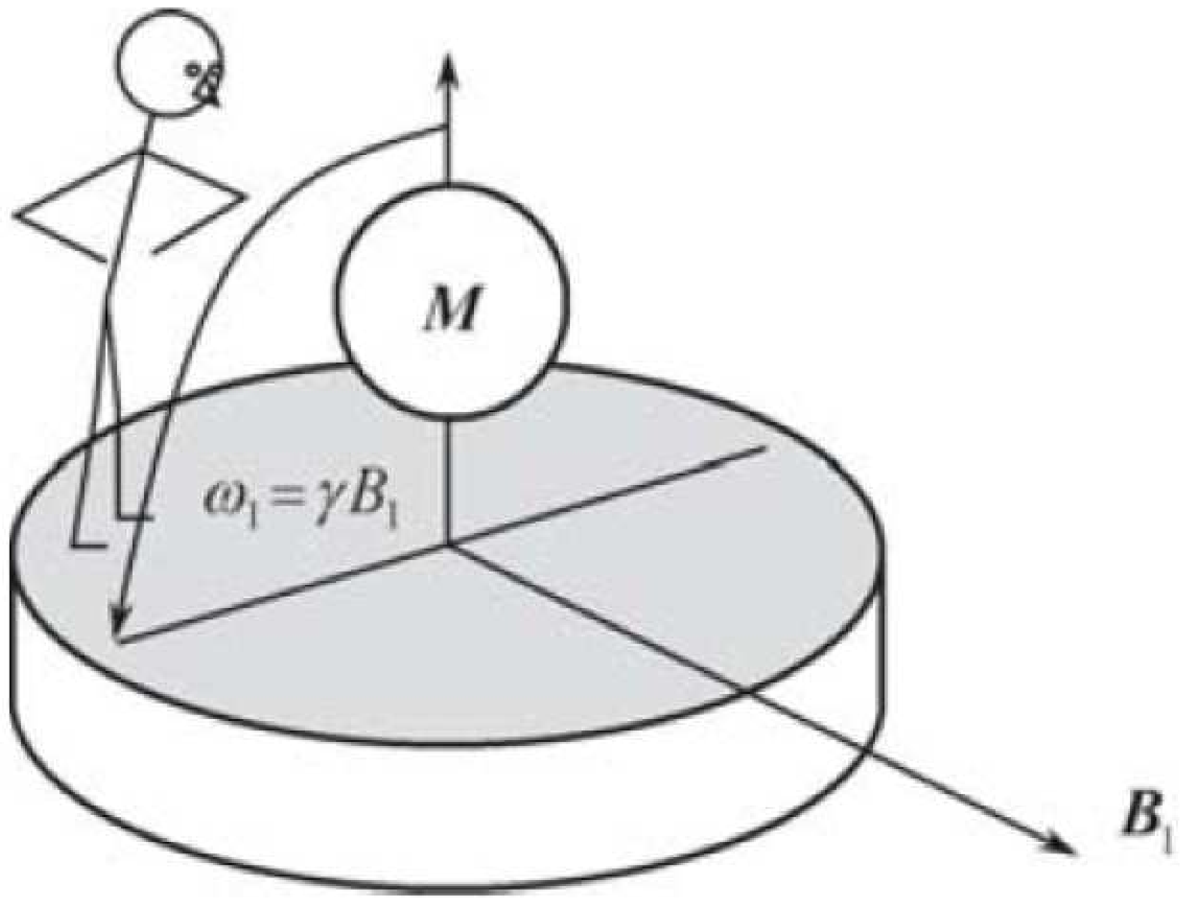

Figure 9: Frame of reference aligned with the magnetic moment $\boldsymbol{M}$ (Zeng, 2009)

Magnetic Resonance Imaging: Principle

- The constant magnetic field in the virtual rotating coordinate system is generated by a varying the field in the constant coordinate system.
- The varying field corresponds to a radio frequency pulse at the Larmor frequency.
- This “knock-off” pulse is also called a 90° pulse.
- During the return to the equilibrium state, a resonance pulse at the Larmor frequency can be measured.

$\rightarrow$ For imaging the hydrogen atoms are knocked off balance and the resonance signal is measured.

Problem: We have not yet discussed localization.
Learn more about that in the next unit.

Topics

Magnetic Resonance Imaging

Summary

- Take Home Messages
- Further Readings

Take Home Messages

- We learned about the general working mechanism of MRI.
- Excitation of atom nuclei in a magnetic field causes them to emit a resonance signal which can be measured.

Further Readings

Two reads for more insight into modalities:

Avinash C. Kak and Malcolm Slaney. *Principles of Computerized Tomographic Imaging*. Classics in Applied Mathematics. Accessed: 21. November 2016. Society of Industrial and Applied Mathematics, 2001. DOI: 10.1137/1.9780898719277. URL: http://www.slaney.org/pct/

Gengsheng Lawrence Zeng. *Medical Image Reconstruction – A Conceptual Tutorial*. Springer-Verlag Berlin Heidelberg, 2010. DOI: 10.1007/978-3-642-05368-9