CHAPTER B1
Spin Behavior

INTRODUCTION

The fundamental concept of MRI is based on the interaction of a nuclear spin with an external magnetic field, $\vec{B}_0$. The dominant nucleus that we image in whole-body MRI is that of hydrogen, i.e., the proton, most of which appears in the form of water. Its interaction with the external field results in the precession of the proton spin about the field direction. Imaging of humans rests on the ability to manipulate, with a combination of magnetic fields, and then detect, the bulk precession of the hydrogen spins in water, fat, and other organic molecules.

The basic motion of the proton spin may be understood by imagining it as a spinning gyroscope that is also electrically charged. It thus possesses an effective loop of electric current around the same axis about which it is spinning. This effective current loop is capable of interacting with external magnetic fields as well as of producing its own magnetic field. We describe the strength with which the loop interacts with an external field, as well as the strength with which the loop produces its own field, in terms of the same "magnetic dipole moment" vector $\vec{\mu}$. The direction of this vector is nothing other than the spin axis itself and, like a compass needle, the magnetic moment vector will tend to align itself along any external static magnetic field, $\vec{B}_0$. In *UNIT B1.1*, we will discuss the magnetic moment and derive its equation of motion. From the equation of motion, we can then quantitatively understand how the magnetic moment precesses about the magnetic field. More importantly, the equation of motion yields the phase expression and the Larmor frequency, which are the key concepts in MRI. At the end of that unit, we will also discuss the gyromagnetic ratios of the electron and other elements.

The precession of the spin becomes complicated when a second magnetic field (in additional to the static magnetic field) is applied to tip down the spin onto the transverse plane (transverse to the static field). This second magnetic field usually rotates as fast as the Larmor frequency in order to offset the Larmor frequency in the rotating reference frame. Thus, the physics related to the phase of the spins and the flip angle through which they are rotated is easy to understand when our viewpoint is in the appropriate rotating reference frame. This is the focus of *UNIT B1.2*.

In MR applications, the magnetic field does not tip down only one spin. Instead, it tips down an ensemble (isochromat) of spins. (On the other hand, neither does it tip down all spins.) Thus, we can simply replace the magnetic moment by the magnetization (magnetic moment density) in the aforementioned equation of motion. The focus of *UNIT B1.3* is to derive the magnetization from an ensemble of spins. Before doing that, we also introduce the historic experiment by Stern and Gerlach by which they discovered the electron spin.

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