Introduction: How Can We Find a Signal to Measure?

As we concluded the previous section, a sample of protons was described by its energy configuration, the distribution among energy levels. The magnetization of the sample was shown as the NMV. Nonetheless, we could not measure the NMV because it was so small relative to the static magnetic field $B_0$. This chapter answers the question: How then can we measure the magnitude of magnetization in the sample?

At Rest, Signal Is Not Detectable

Faraday’s law of induction tells us that moving charge will induce a magnetic field. It is conversely true that a moving magnet will induce an electric field. In the presence of a conductor (a loop of wire—AKA antenna—that we will call a receiver coil), a voltage will be induced by the moving magnet. This is exactly how we measure the signal in NMR and MRI; the magnetization of the sample induces voltage in a receiver coil. In our case, however, what voltage will be induced in a receiver coil placed adjacent to our sample of protons that has been placed into a static magnetic field $B_0$? Surprisingly, perhaps, we will measure absolutely nothing! This is because the net magnetization of our sample (the NMV) is stationary. Remember that, although each individual spin is precessing about $B_0$ with a frequency of $\omega_0$, because the spins precess with random phase, all transverse magnetization cancels. If the net magnetic field of our sample (i.e., NMV) does not move, no signal (voltage) will be induced in the coil (wire).

Net Transverse Magnetization Is Detectable

If the sample of protons can be altered so that there is nonrandom phase of precession of the individual spins that comprise the NMV, there will be a net transverse component to the NMV. The NMV will no longer be parallel to $B_0$ but rather will be oriented at an angle with respect to $B_0$. We call
this the flip angle or angle of nutation. Most importantly, because there is now net $M_r$, the NMV itself will now precess about $B_0$. The NMR signal that we measure is induced by the transverse component of the NMV (the portion that is perpendicular to $B_0$). Notice again that the NMV is no longer stationary; it precesses around the axis of $B_0$. The frequency of precession, of course, is $\omega_0$.

Generating Net Transverse Magnetization

How then do we get the NMV to flip and generate net transverse magnetization?

The short answer is that flip of the NMV results when energy is added to the spin system, shifting it into a higher-energy configuration. The new orientation of the NMV (flipped) is the observable manifestation of this higher-energy configuration. To efficiently transfer energy onto the spins in our sample, we exploit the concept of resonance.

Resonance

The basis of resonance—a major scientific contribution of Nikola Tesla—is that everything has a unique “natural frequency” at which it will oscillate under a given set of ambient conditions. Think, for example, of a “C” tuning fork. When we add energy to the tuning fork by striking it against a desktop, it oscillates at a unique frequency, a C note. If we place a second C tuning fork adjacent to the ringing C fork without making contact, the second fork will also begin to ring. This is due to resonance; sound energy from the ringing fork is so efficiently transferred through the air that contact is unnecessary. If we next place an “A” tuning fork in proximity to the ringing C fork, it will not ring. This is because the energy source (the C fork) and the receiver (the A fork) do not have the same natural frequency. Without a precise match of frequencies, resonance is absent and efficient transfer of energy cannot occur.

One of my favorite examples of resonance was featured in a famous commercial for Memorex cassette tapes. When Ella Fitzgerald, a professional vocalist, sings a high note that happens to match the natural frequency of a nearby crystal glass, sound energy from her voice is deposited with such great efficiency that the glass shatters. Of course, energy not matching the natural frequency of the crystal—such as a blow from a hammer—can also shatter the glass; it makes up for the mismatch in natural frequencies with amplitude. Consider the difference in amplitude between the sound wave and the hammer blow.

Another example of resonance had more dramatic consequences. In 1940, the Tacoma Narrows Bridge opened for travel across Puget Sound, Washington. The suspension design was state of the art and designed to