1.9: The Nuclear Resonance Signal

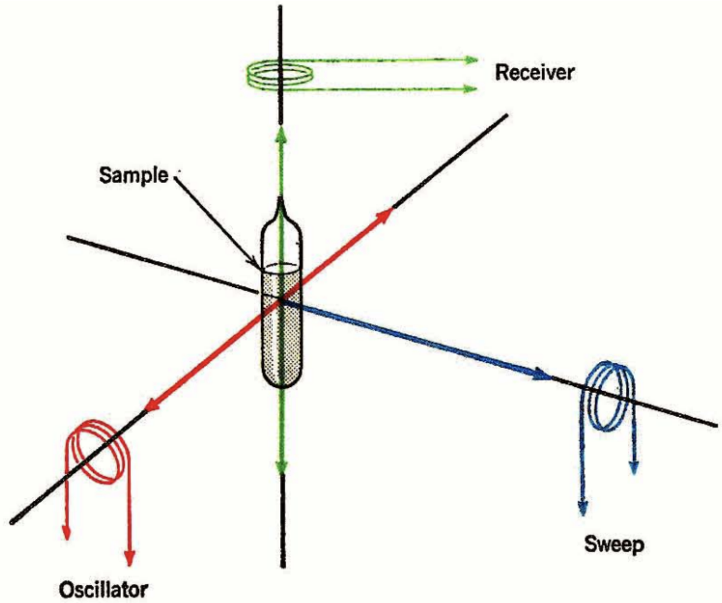

Fig. 1-5. **Magnetic forces operating on sample in an NMR spectrometer.**

The operation of the nuclear magnetic resonance spectrometer may now be discussed in terms of the magnetic properties of nuclei outlined above. As a quick review, we note as before that the sample is subjected to (1) a large magnetic field varied by the sweep generator and directed along the Z axis and (2) an alternating magnetic field along the X axis produced by the oscillator coil (Fig. 1-5). The receiver coil is oriented so as to respond to an alternating magnetic field along the Y axis, and the oscillator must induce a component of Y magnetization in the sample if a signal is to be picked up by the receiver. At the nuclear level, the situation is as shown in Fig. 1-6. In the first place, we note that an assemblage of magnetic nuclei placed in a magnetic field undergo relaxation and reach aa equilibrium distribution in which there is a slight excess with the magnetic quantum number +1/2 This excess of nuclei with m = +1/2 combine to give a small macroscopic resultant magnetization in the Z direction. In addition, each nucleus acts as if it were precessing around the magnetic field axis with the angular velocity ωo (equal to γH_o). At the beginning of a nuclear magnetic resonance experiment, the nuclei will have no phase coherence and the excess of nuclear magnets with m = +1/2 is represented graphically by having the individual magnetic vectors distributed evenly over the surface of a cone whose axis coincides with the direction of the magnetic field. In this situation, there will be no net X, Y component of nuclear magnetization.

Consider the nuclei to be now subjected to an alternating magnetic field in the X direction produced by the rf oscillator. This field will have no net component in the Y direction, but we can consider that it is made up of two equal magnetic vectors rotating at the same velocity in opposite directions with phase relations so that they exactly cancel each other in the Y direction. One of these vectors will be rotating in the same direction as the nuclear magnets precess while the other will be rotating in the opposite direction. Of course, the field which is rotating oppositely to the direction of nuclear precession will not interact with the nuclei because it cannot stay in phase with them. However, the field which is rotating in the same direction can stay in phase with and tend to flip over the nuclear magnets, provided it has the same angular velocity (see Sec. 1-6).

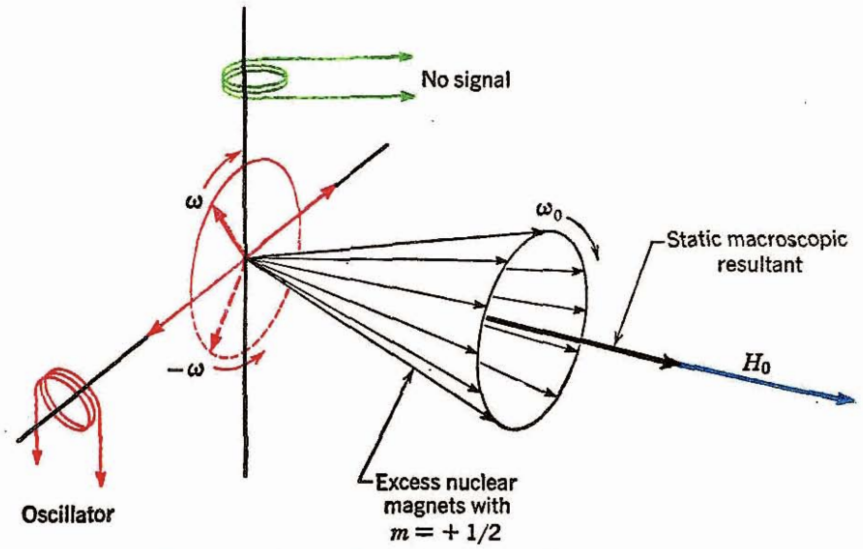

Fig. 1-6. Start of nuclear induction experiment.

In a typical nuclear magnetic resonance experiment, we change the precession frequency of the nuclei by varying the applied magnetic field and keep the oscillator frequency constant. At some value of the field, the nuclear precession frequency becomes equal to the frequency of the rotating field vector produced by the oscillator, and energy may then be transferred from the oscillator to the nuclei, causing some of them to go to the higher energy state with m = -1/2. At the same time, the rotating field vector acts to tip the vectors of the individual nuclear magnets, with which it is 90" out of phase, away from the field axis and thus causes the axis of the cone of vectors to "wobble" around the field axis at the precession frequency. This has an effect such as would result from bunching the nuclear vectors as shown in Fig. 1-7, so that the macroscopic resultant is moved away from the field axis and produces a rotating component of magnetization in the X and Y directions which, of course, precesses around the field axis with the same angular velocity as the individual nuclei. This alternating field in the Y direction induces a current in the receiver coil and thus generates an NMR signal.

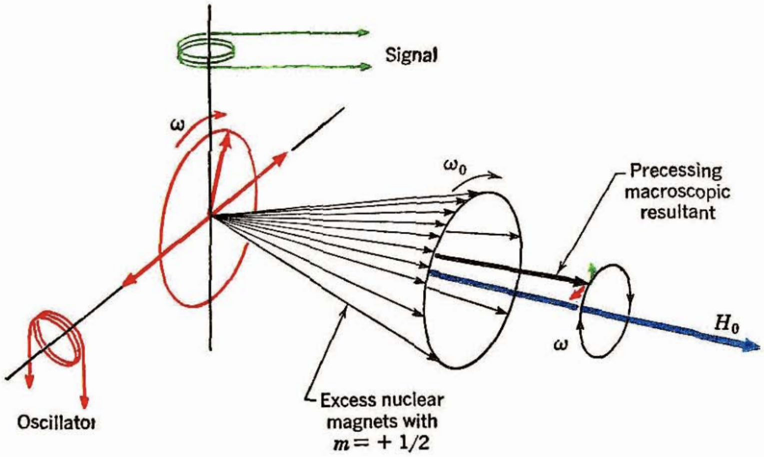

Fig. 1-7. Conditions at resonance $\omega_0 \cong \omega$.

As the magnetic field is increased through action of the sweep generator, the nuclei increase their precession frequencies and drop out of phase with the rotating field vector. At this point, transverse and longitudinal relaxation return the nuclear magnetization of the nuclei in the X, Y, and Z directions to the equilibrium values. As the Y magnetization decreases by transverse relaxation, the signal dies away in the receiver.