Magnetic Resonance and Medical Imaging

4th year /Medical Physics

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Free Induction Decay

When a patient is placed in the B0 magnetic field, the patient becomes polarized (see Figure 1-4). The proton magnetic dipoles have aligned with B0, and the alignment is symbolized with one large arrow, Mz (Figure 1-8). This arrow represents a vector quantity called net magnetization.

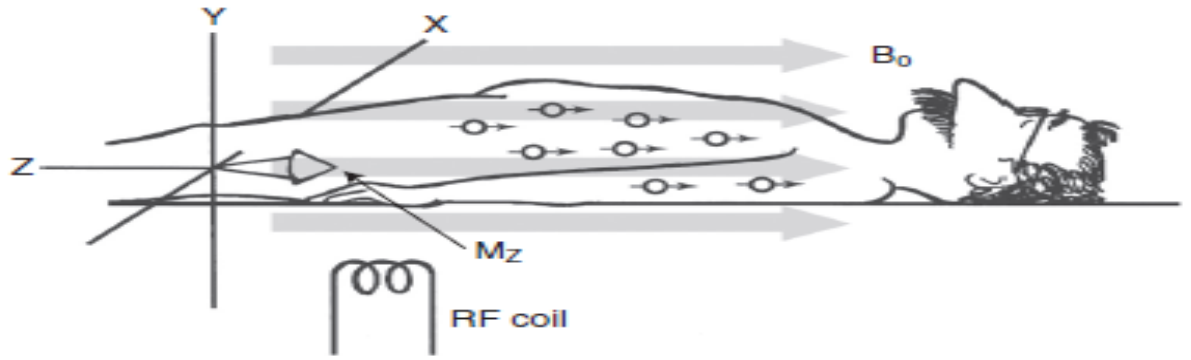


FIGURE 1-8 Net magnetization along the *Z*-axis is represented by M_z and the *large arrow*.

The symbol MZ represents net magnetization that lies along the Z-axis. The MRI experiment begins with the emission of a pulse of RF energy at the Larmor frequency from an inductor, called an RF coil, into the patient (see Figure 1-8). For hydrogen imaging with a magnetic field of 1 T, the RF coil is tuned to 42 MHz.

If one plucks نقر a string of a guitar and a harp (ضرب على وتر واحد) قيثار is standing nearby, one of the strings on the harp will begin to vibrate (Figure 1-9); the other strings will remain still. The harp string vibrates because that string has the same fundamental resonance as the plucked guitar string. The “R” in MRI stands for resonance. The RF pulse transmitted into the body must be at the resonant frequency of the precessing hydrogen nuclei for energy to be transferred and imaging to occur.

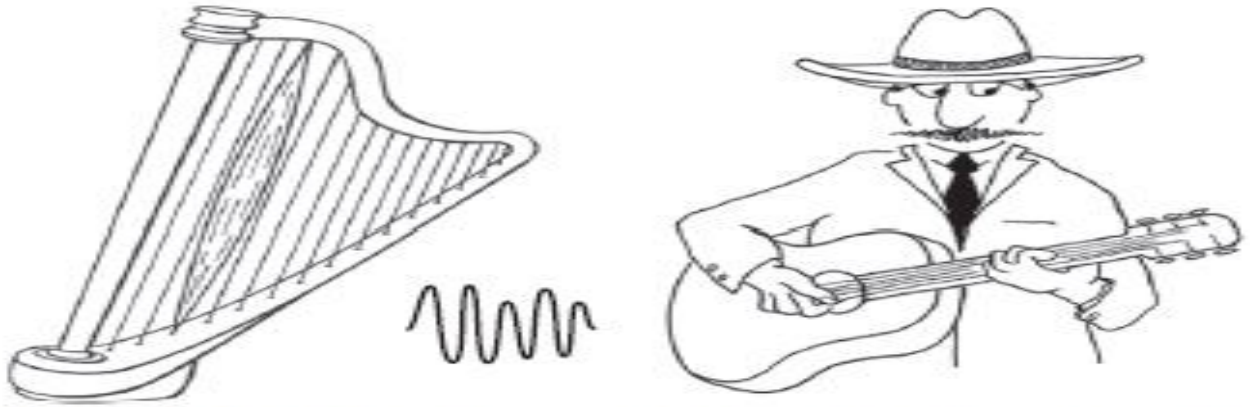
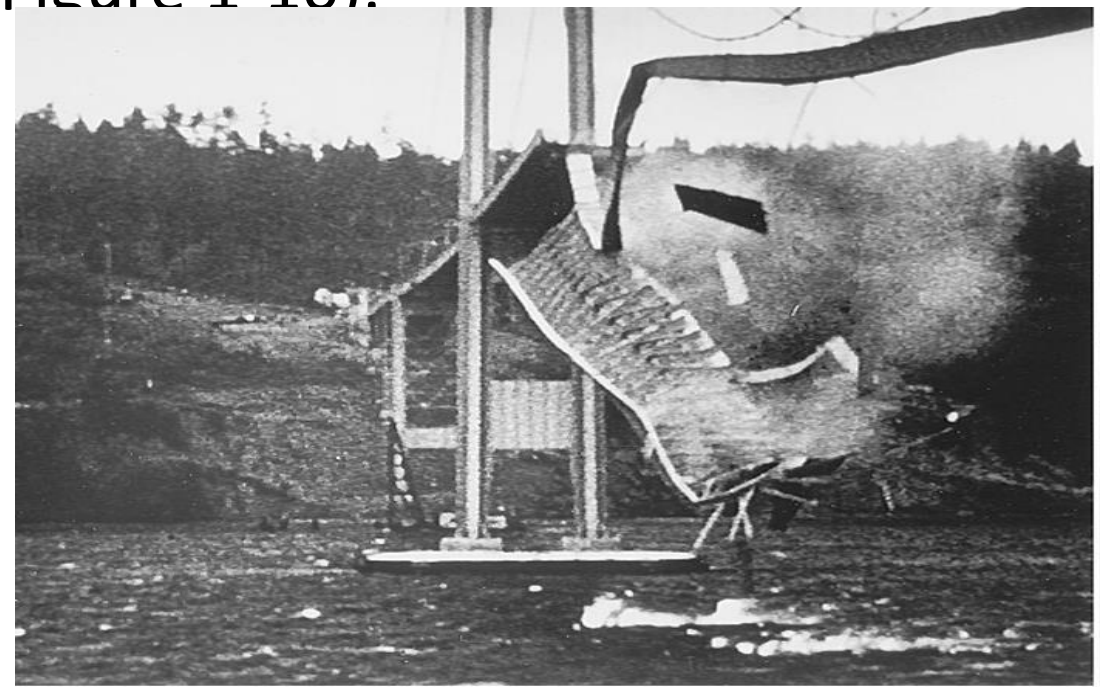


FIGURE 1-9 Plucking one guitar string causes only one string of a nearby harp, which has the same fundamental resonance, to vibrate.

- Most objects in nature have a fundamental resonance. Energy transfer is always most efficient at resonance. For example, at a large hote in Kansas City several years ago, people were dancing on a suspended bridge like walkway. They hit a resonance that was fundamental to the walkway. The walkway collapsed, killing several people.
- For this reason, marching military personnel are instructed to break cadence when crossing a bridge. A third example is the collapse انهيار of the Tacoma Narrows suspension bridge when it was subjected to harmonic buffeting winds (Figure 1-10).



With net magnetization in the Z direction, not only are the proton magnetic dipoles aligned, but each individual proton is precessing at the Larmor frequency (Figure 1-11). When the RF signal is pulsed at resonance into the patient, the energy state of many protons is changed.

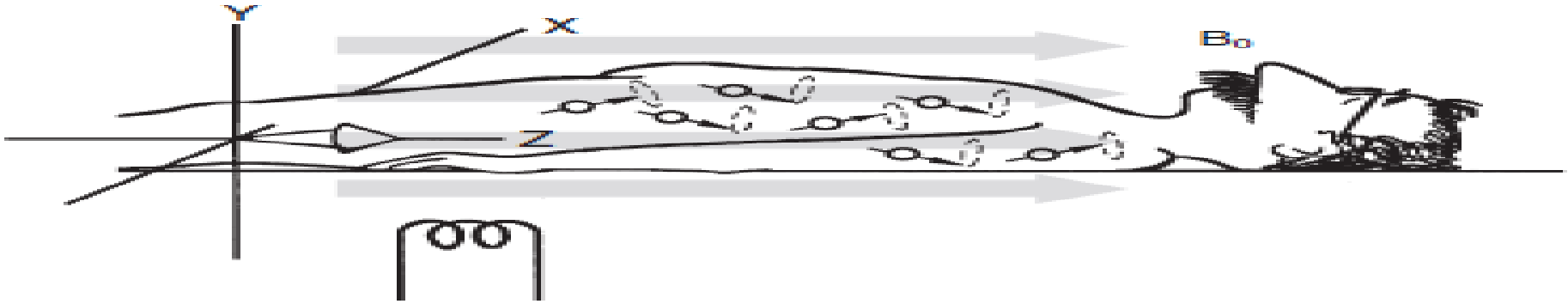
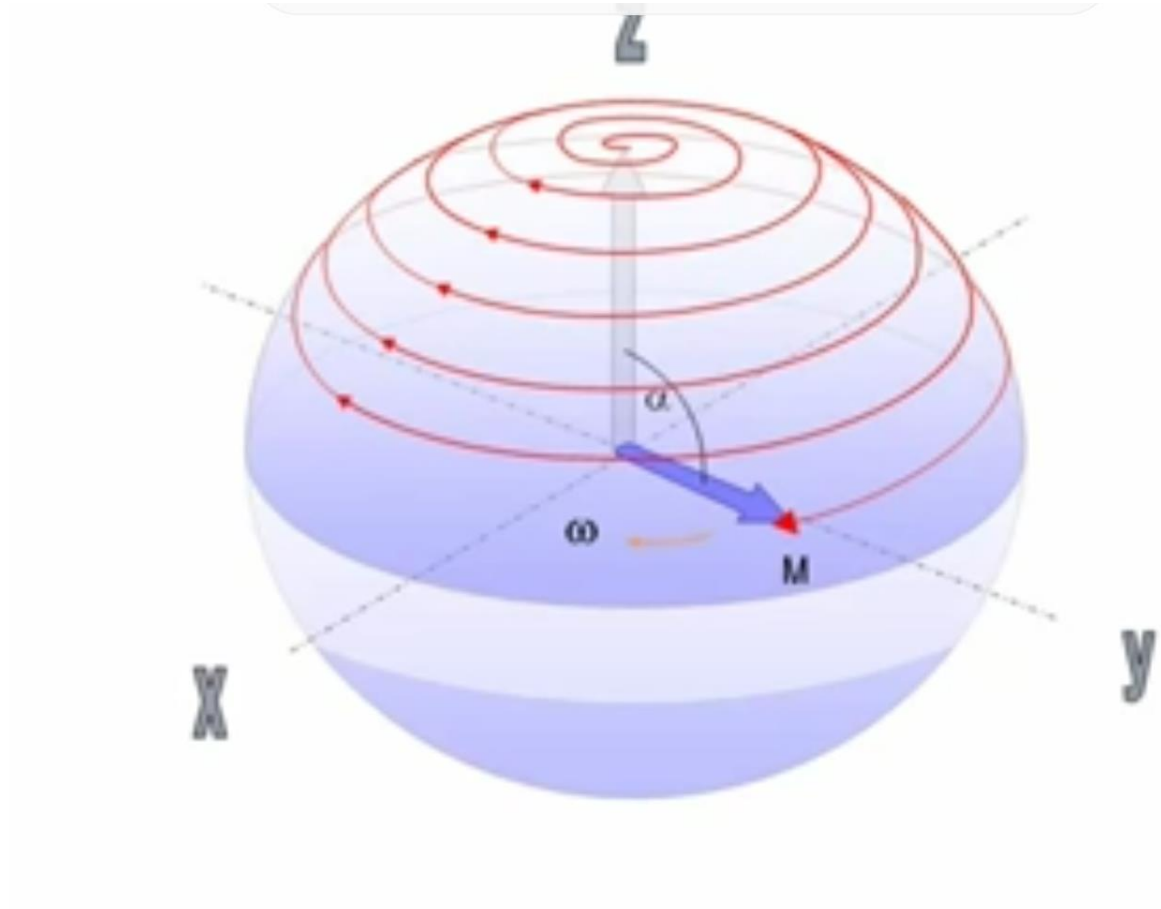
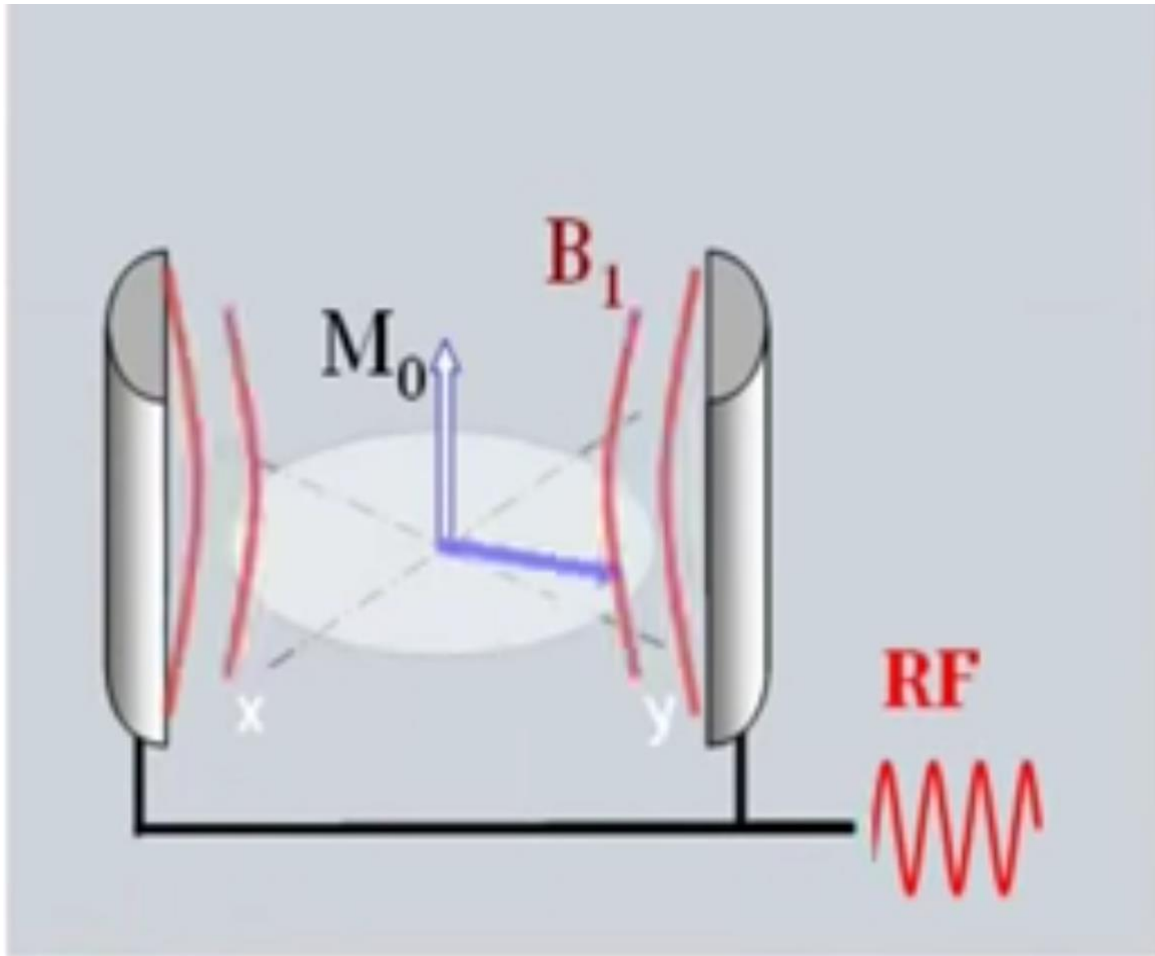
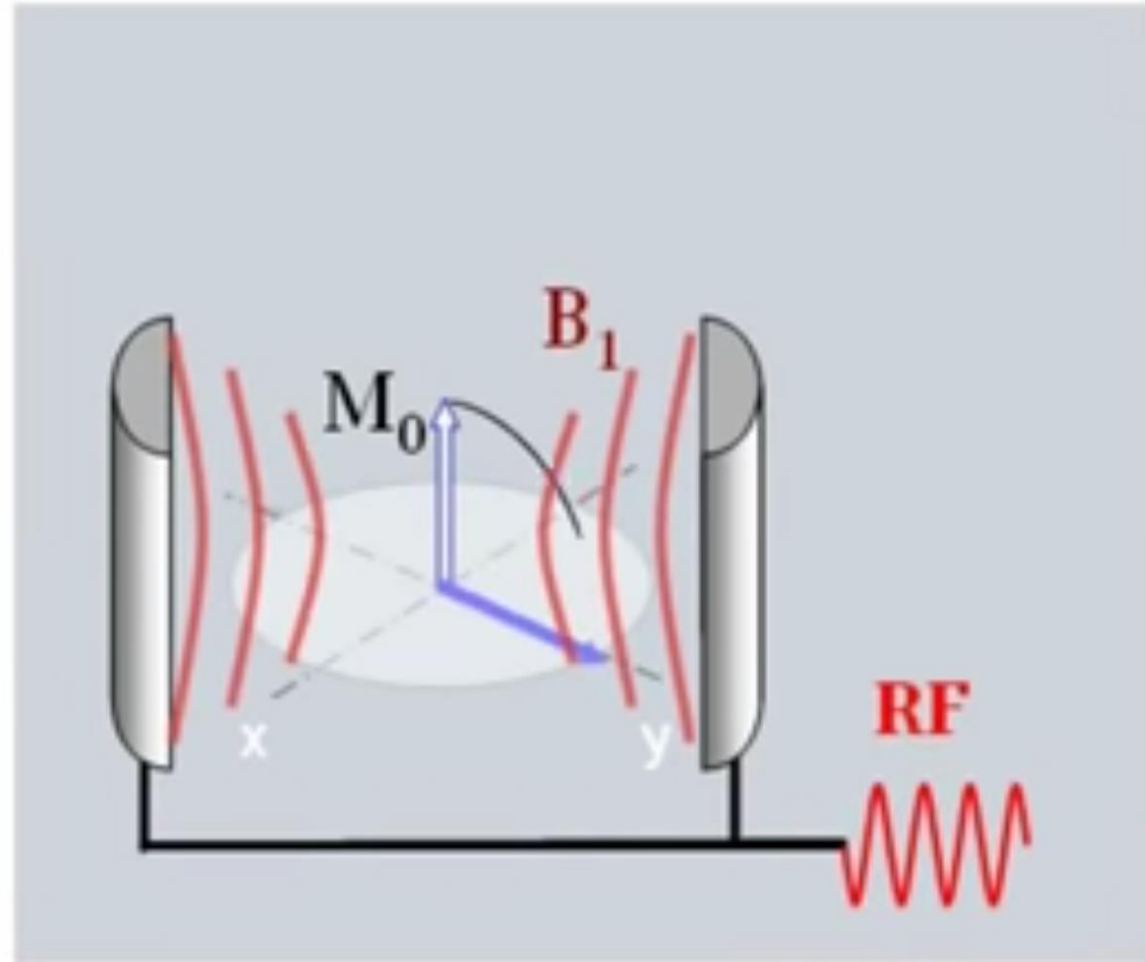


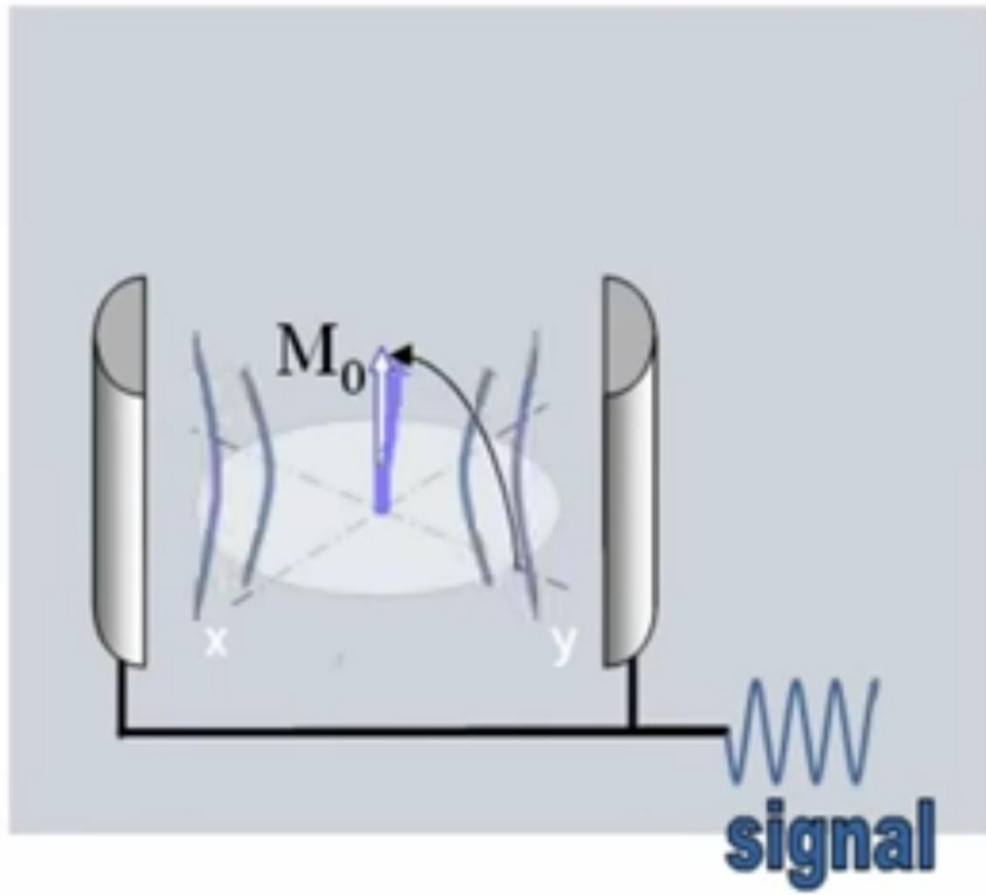
FIGURE 1-11 Placing a patient in a magnetic field (B_0) polarizes the patient and causes each proton dipole to precess randomly.

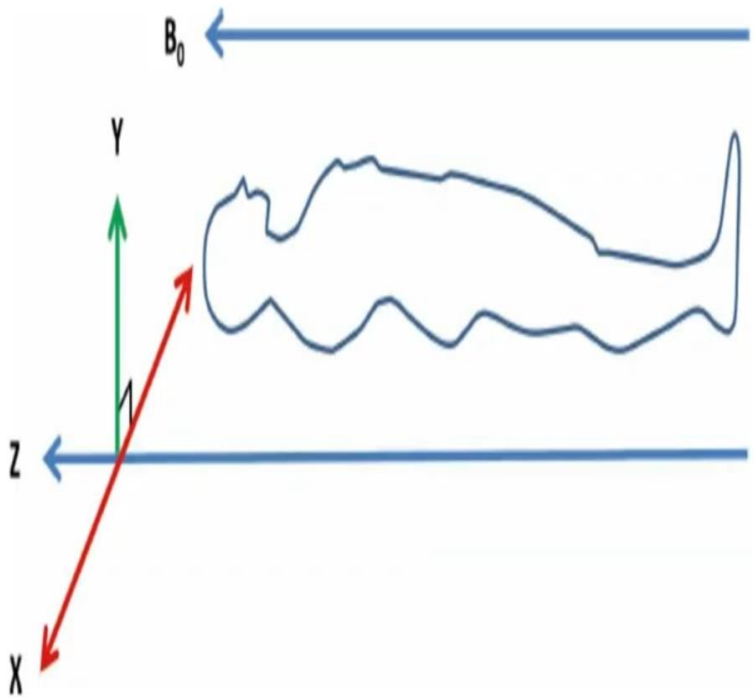
The net magnetization, due to all of the protons, is said to “flip” toward the negative Z direction, while still precessing about the Z-axis (Figure 1-12). This precession is always perpendicular to Z, in the XY plane, and if initially all of the spins are aligned along the same direction in the XY plane, we have created a condition called phase coherence of the spins. This is the condition in which the most MR signal can be generated and received.


z
α
ω
M
x
y


B1
M0
x
y
RF


B1
M0
x
y
RF

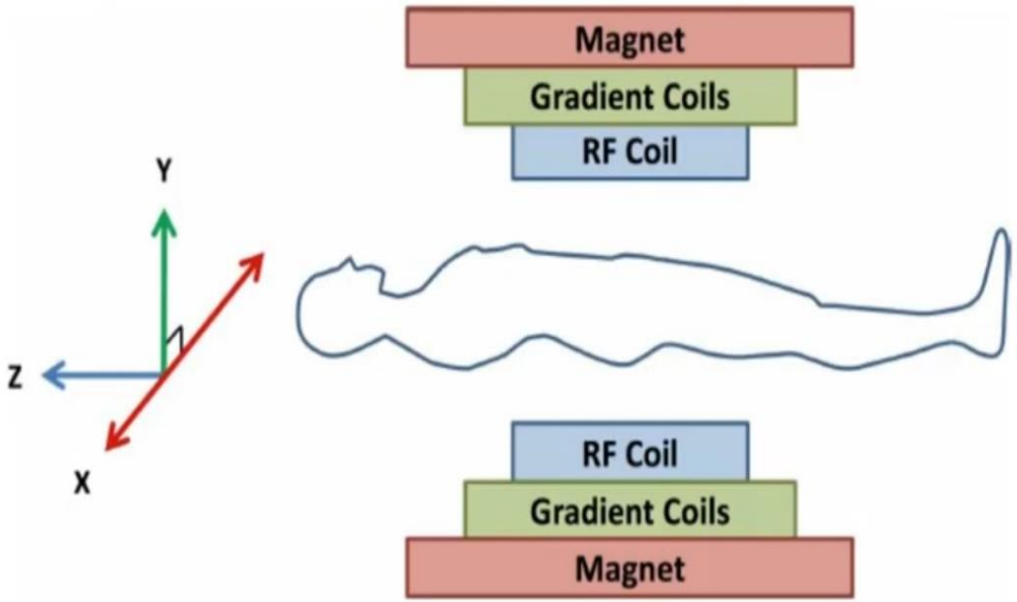

M_0
x
y
signal



Axes of an MRI machine

There are several components to an MRI machine.

1. Superconducting electromagnet



MRI machine magnets

2. Shim coils (not shown)

- Uniformity

3. Gradient coils

- Change M.F in x,y and Z direction for spatial encoding .

4. RF (radiofrequency) coils

1. Standard body coil (transmit and receive): permanent part of the scanner. Used to image large parts of the body
2. Head coil (transmit and receive): incorporated into a helmet and used for head scans
3. Surface (or local) coils (receive only): these are small coils applied as close to the area being imaged as possible e.g. arm coils, leg, orbits, lumbar spine coils etc.
4. Phased array coils: multiple receiver coils that receive the signals individually but are then combined to improve the signal-to-noise ratio
5. Transmit phased array coils

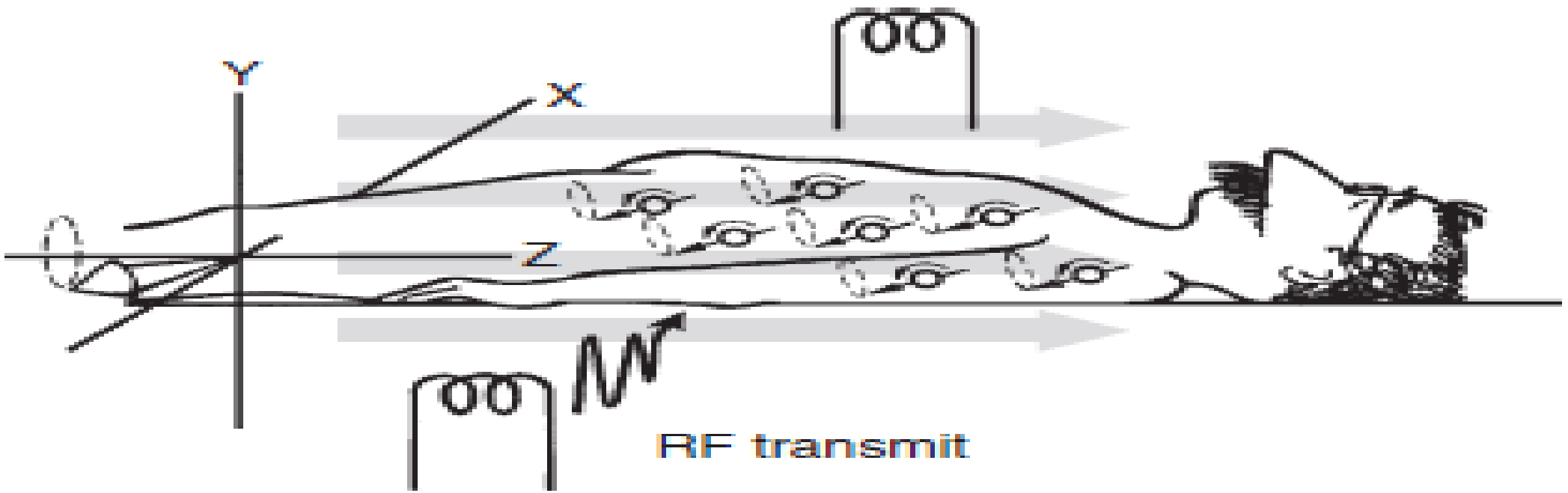


FIGURE 1-12 Net magnetization changes along the *Z* direction and the protons precess in phase when a proper radiofrequency *(RF)* pulse is transmitted into the patient.

- **When RF is pulsed into the patient, the protons individually flip and give up their energy to the patient while continuing to precess. Then, as a group, the net magnetization grows to its normal state in the positive Z direction.**
- **The normal state is called the equilibrium magnetization state because the protons are at equilibrium in the Bo magnetic field. As the individual protons return to equilibrium, the net magnetization precesses around the Z-axis and slowly returns (relaxes) back toward equilibrium (Figure 1-13).**

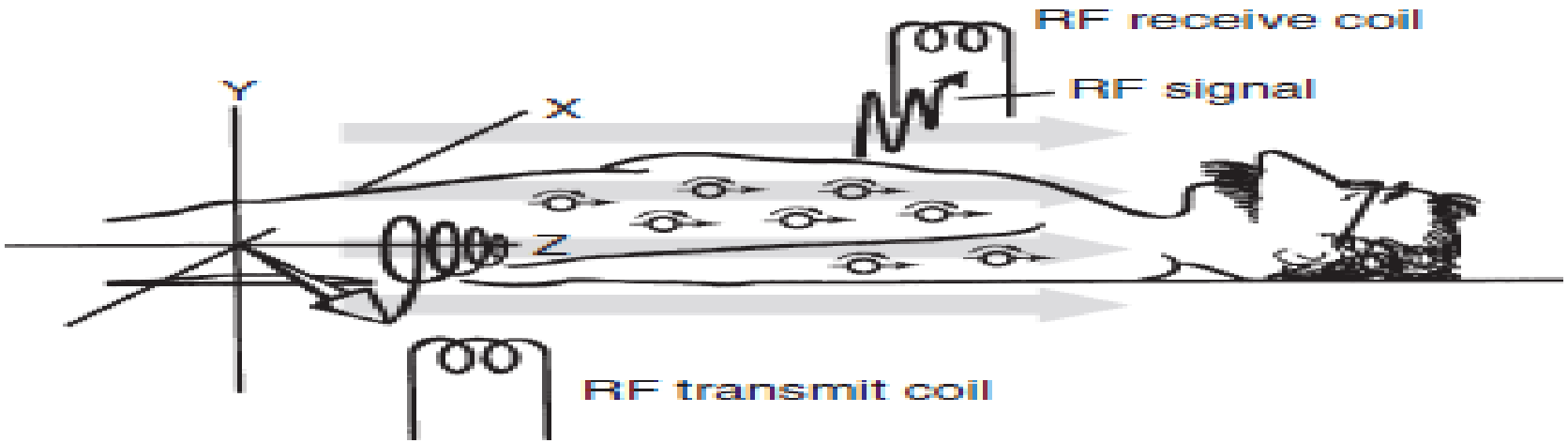


FIGURE 1-13 Precessing net magnetization induces a radiofrequency *(RF)* signal in a receiving coil. That RF signal is called a *free induction decay*.

- To a disinterested observer, such as the RF receiving coil shown in Figure 1-13, such precession is not obvious.

- Only a magnetic field that first approaches and then recedes harmonically is observed. With any moving magnetic field, an electric current can be induced in a properly designed coil.

- The induced current represents a radio signal emitted by the net magnetization created by the nuclei in the patient. This signal is called a free induction decay (FID).

- The RF coil surrounding the patient receives an oscillating signal that decreases with time (Figure 1-14). The signal decreases with time as the proton spins begin to lose phase coherence or dephase.

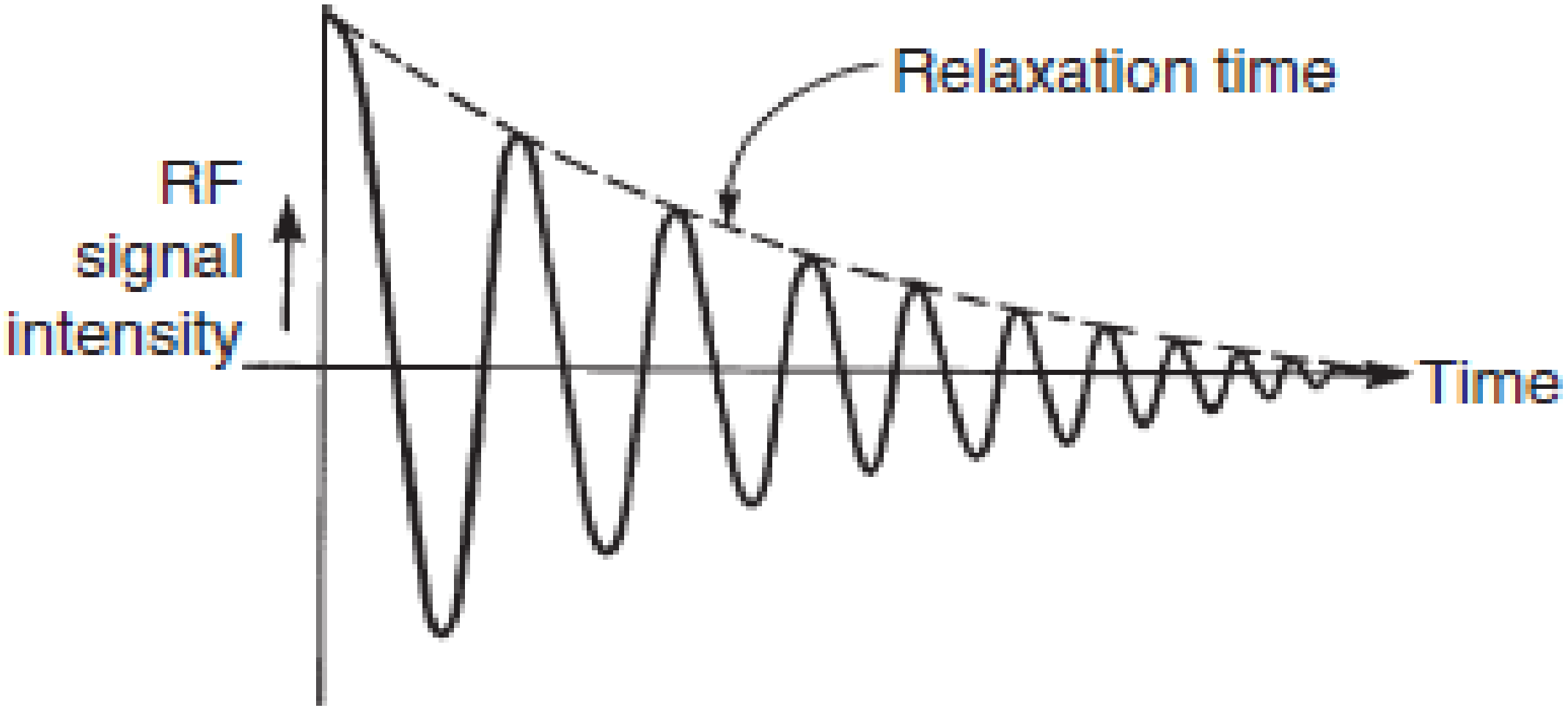


FIGURE 1-14 The free induction decay is a decreasing harmonic oscillation of the Larmor frequency.

- The time constant that describes this process is known as a relaxation time, specifically T2, which is also called the transverse relaxation time. It is similar to the decay constant that describes radioactive decay.

- Two such relaxation times exist in MRI. The other is the T1 relaxation time that describes the rate of the magnetization increasing back to equilibrium.

- T1 and T2 can generally be considered to be independent of one another and represent two different processes occurring at the same time but often at different rates