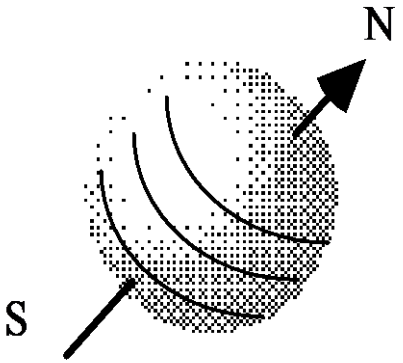
Fundamental MRI Principles Module Two



Nuclear Magnetic Resonance

- There are three main subatomic particles:
  - protons positively charged
  - neutrons no significant charge
  - electrons negatively charged
- Protons and neutrons (nucleons) are located in the nucleus and make up most of the atom's mass.
- Electrons orbit the nucleus of the atom.

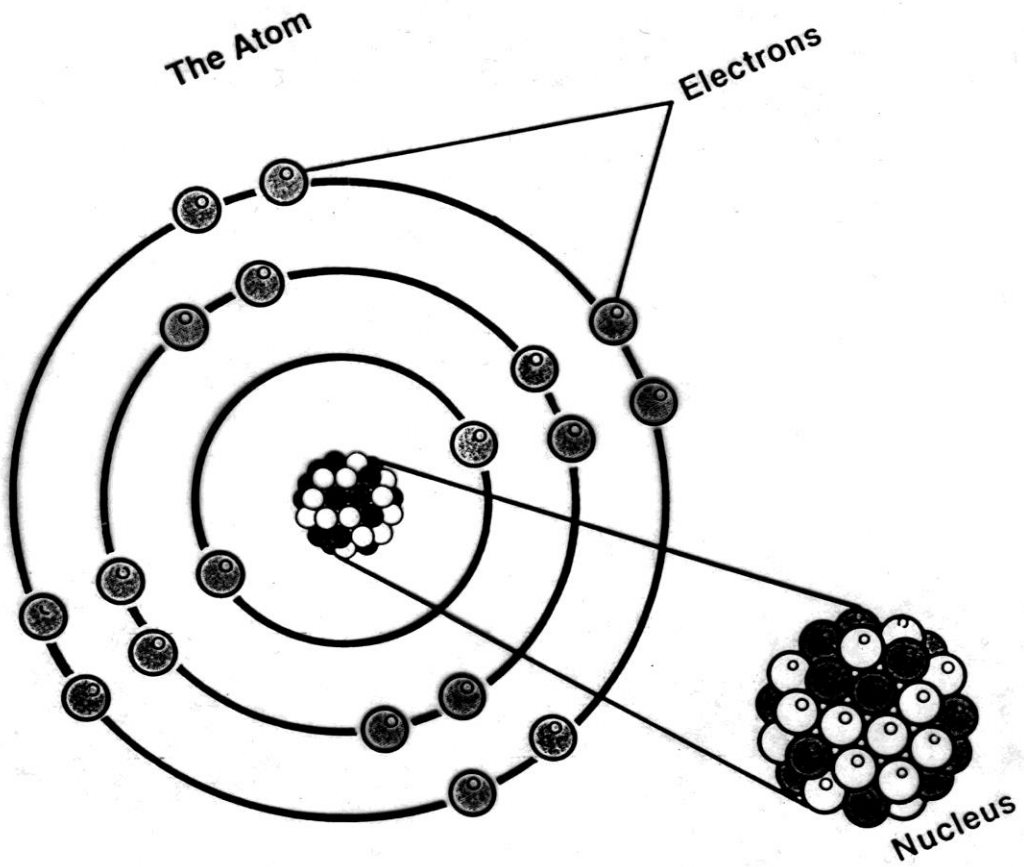
X-ray

Electrons

MRI

Hydrogen

Protons



Properties

- The chemical properties of an atom depend on its electron structure.
- The physical properties depend on the nucleus accounting for most of the atom's mass.
- Atoms which have magnetic properties are those with unpaired nucleons.

Angular Momentum

- If the nucleons are paired the angular momentum is zero and there is no net spin.
- If the nucleus contains unpaired protons, neutrons, or both, the nucleus will have net spin and angular momentum.
- Angular momentum describes the rotational motion of a body.

Hydrogen

- Hydrogen (^{1}H) with one proton (no neutrons), is the principle isotope best suited for MRI.
- It has the largest magnetic moment among all naturally occurring nuclei and largest isotopic abundance (almost 100%).
- It has the largest chemical abundance in the form of water and fat than any other element.

Nuclear Characteristics

- There are other atoms that have unpaired nucleons.

- However, because the number of isotopes and magnetic sensitivity are low, when imaged will result in low signal return and poor image quality.

Magnetic Properties of Selected Nucleus

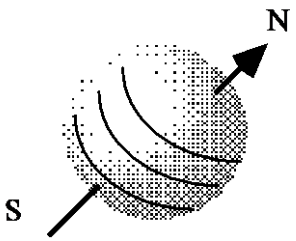
Nucleus	Spin	Relative Abundance	Relative Sensitivity
^{1}H	1/2	99.98	1.0
^{2}H	1	0.015	0.0096
^{13}C	1/2	1.11	0.016
^{23}Na	3/2	100	0.093
^{31}P	1/2	100	0.066
^{19}F	1/2	100	0.830

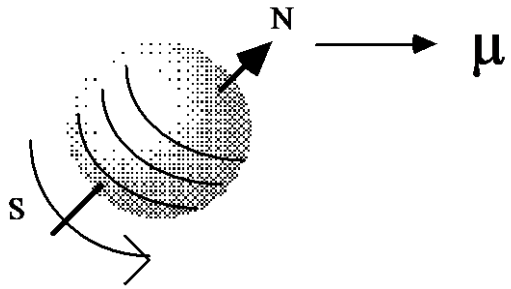
Reference: Lufkin, RB., The MRI Manual. Yearbook-Mosby, 1990.

Magnetic Moment

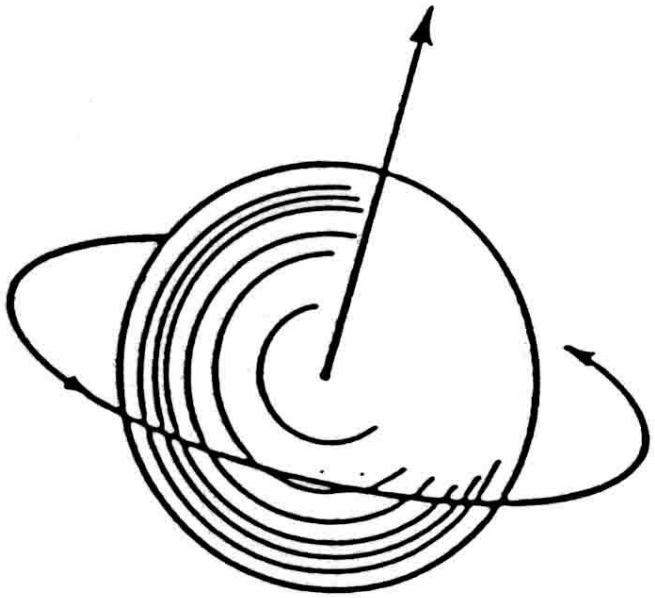
- Think of each hydrogen proton as a tiny spinning magnet.

- Since nuclei bear charges, their spinning produces what is called a magnetic moment (μ or m).





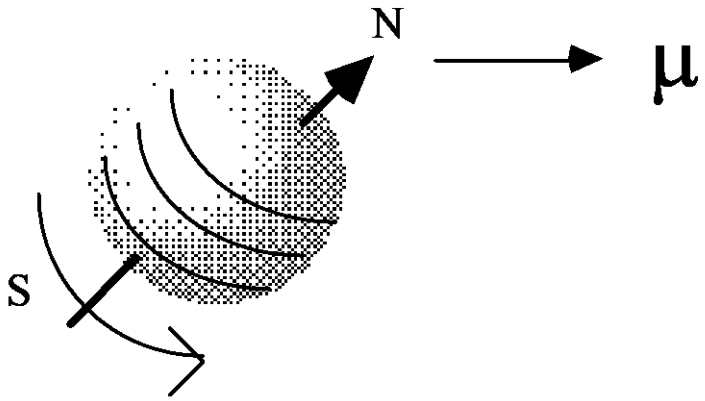
Proton



Spin

Magnetic Vector

- Magnetic moment (m) expresses the strength and direction, in physical vector quantities, of the magnetic field surrounding the nucleus.



Precession

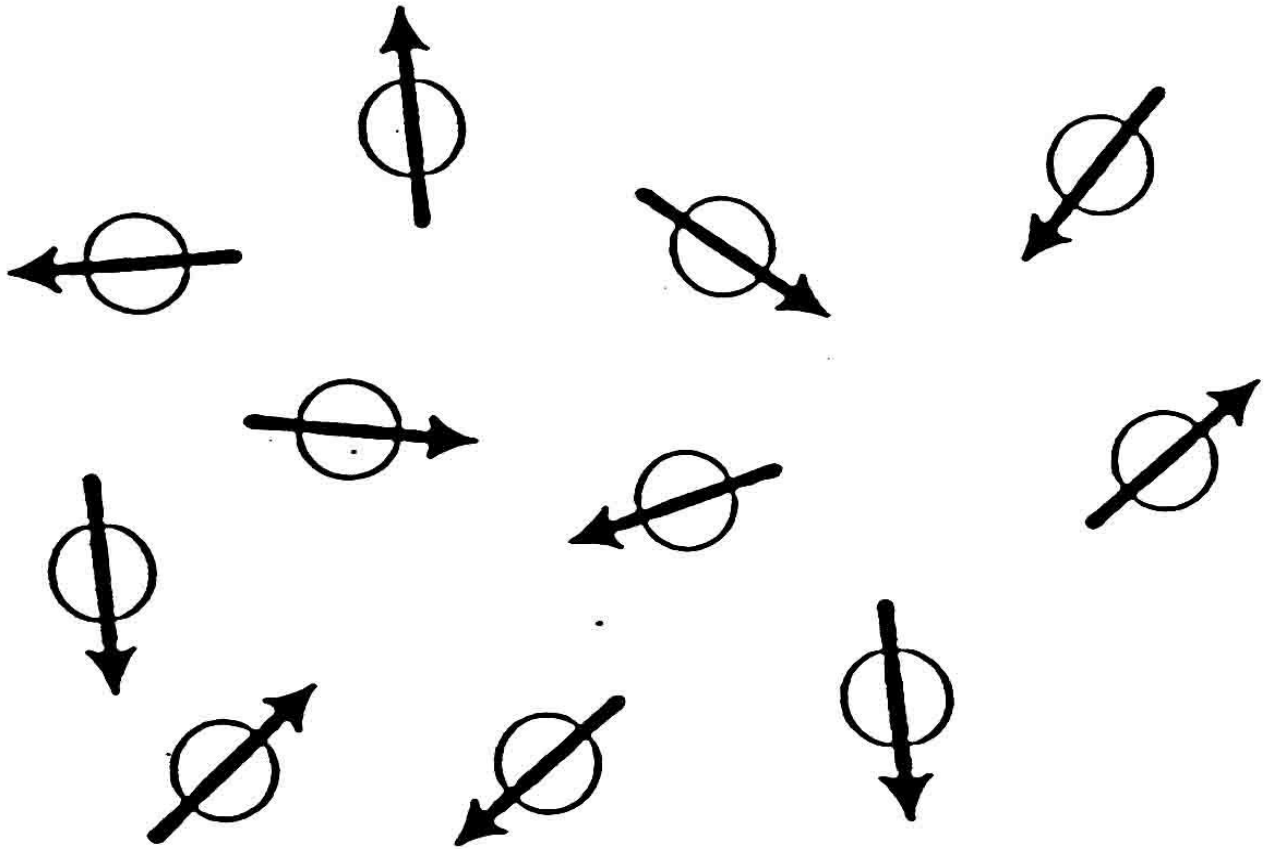
- When the human body is exposed to the earth's gravity, the body's hydrogen atoms, among other atoms that have magnetic moments will precess:
  - a wobbling motion of the spinning atom that occurs when exposed to an external magnetic field.

- The atoms will not precess in phase nor will they align with one another due to the weak magnetic field of the earth (0.5 - 0.7 G).

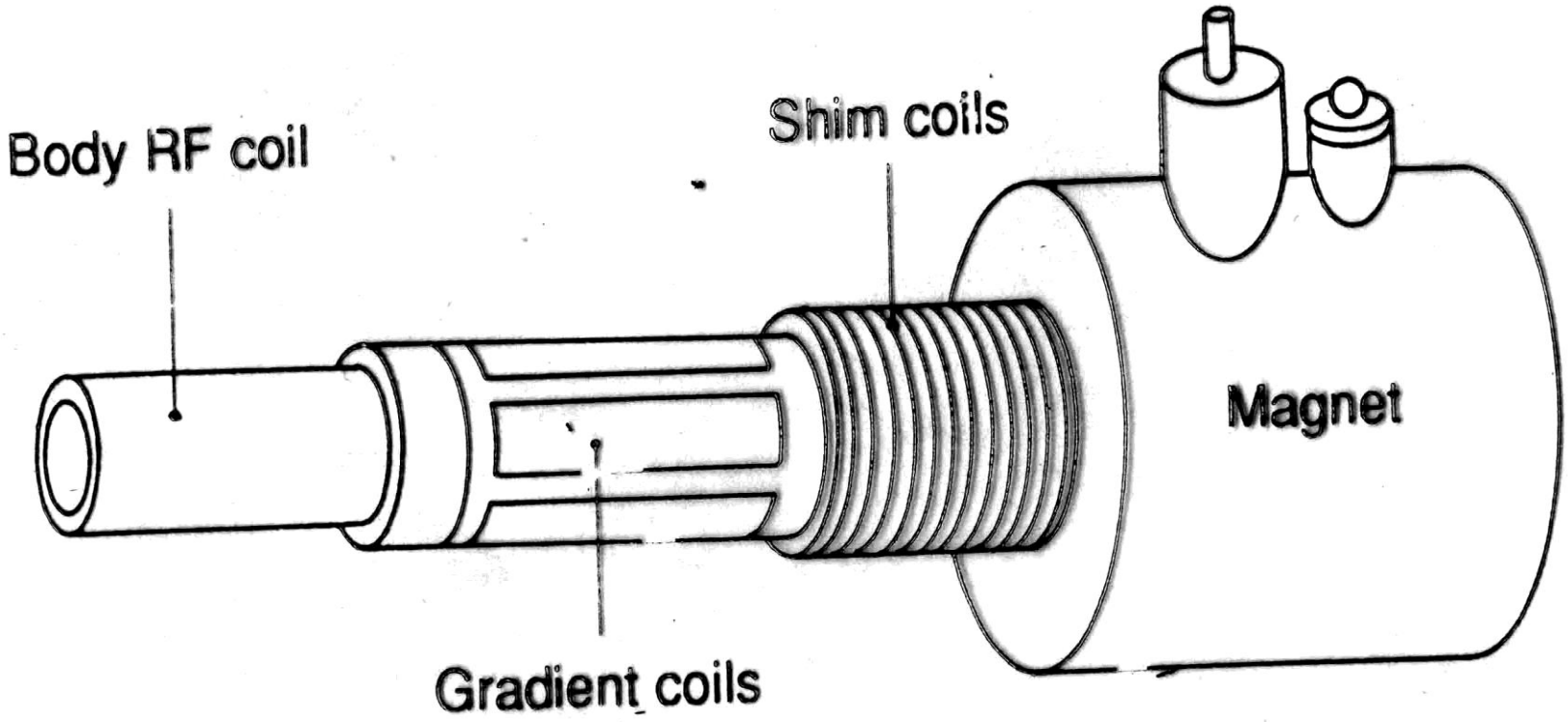
Magnetic Effect

- The atoms will remain randomly aligned until a strong enough external force causes them to align in a particular direction.

No External Field



Superconductor



Magnetism

- There are several sources that provide magnetism used to perform MRI.

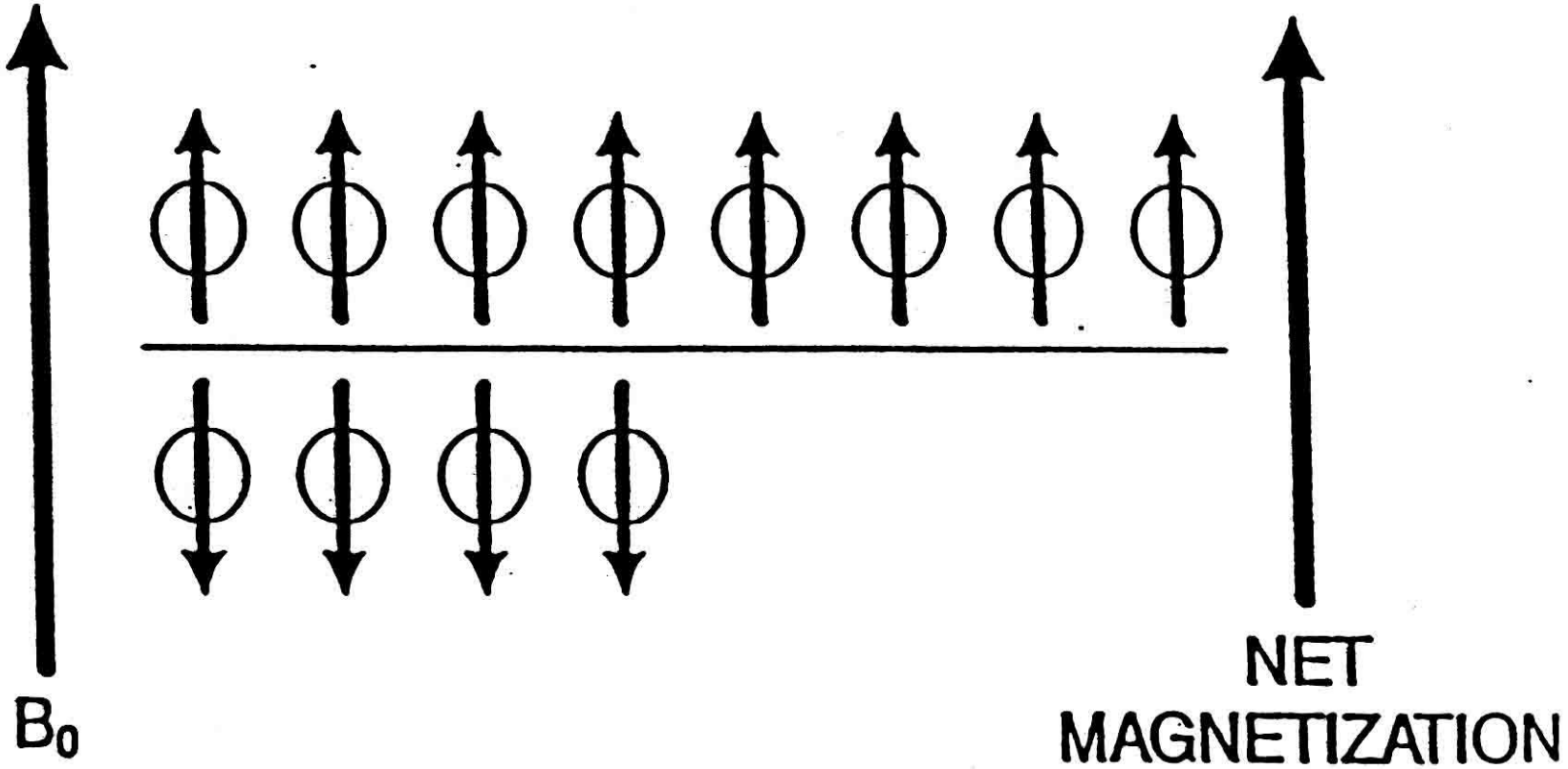
Source	Magnetism
Main magnet	static
Gradient coils	gradient (TVMF)
RF coils	radio frequency (oscillating)
Hydrogen ($_1$H)	magnetic moment

Magnetic Field

- The magnetic field created by the main magnet is bipolar (north and south pole).

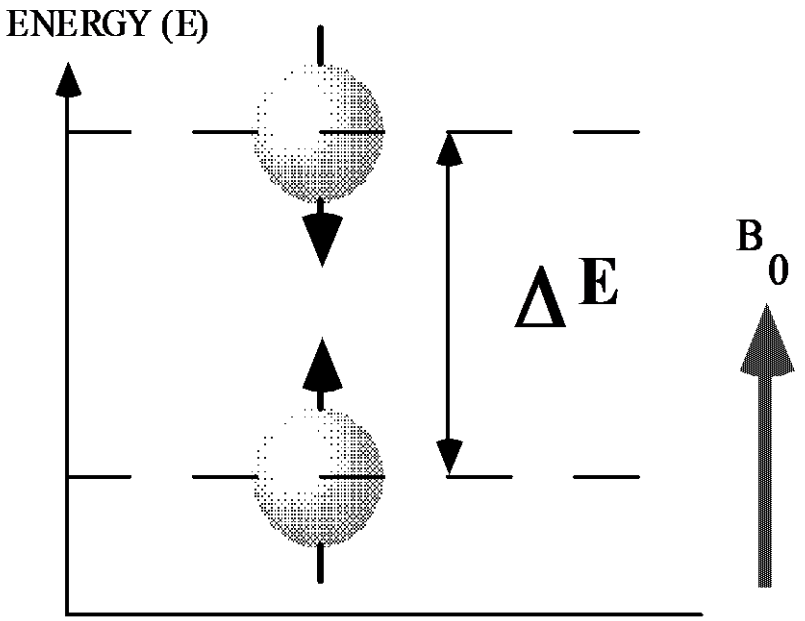
- North (Spin Up) = Parallel
- South (Spin Down) = Anti-parallel

External Field Applied



Magnetic Field

- Parallel and anti-parallel energy levels differ based on the thermal energy (^{2}E) generated during random collision of protons.



Protons pointing parallel are at a slightly lower energy level than those pointing anti-parallel.

Net Magnetic Vector

- Parallel atoms cancel like charges in the anti-parallel state producing an excess along the direction of the static magnetic field producing a net magnetic vector (M_0).

Larmor Frequency

- Hydrogen atoms do not align precisely with the axis of the applied magnetic field. They wobble or precess a few degrees off the central axis.

- The frequency of this precession is known as the Resonant or Larmor Frequency, after the British physicist Sir Joseph Larmor.
  - The frequency is proportional to the strength of the applied magnetic field.

Larmor Equation

- We can calculate the resonant frequency if we know the strength of the applied magnetic field, B_0.

$$\omega_0 = \gamma B_0$$

The Larmor Equation

Larmor Equation

- We can calculate the resonant / precessional frequency if we know the strength of the applied magnetic field, B_0.

$$\omega_0 = B_0 \gamma$$

The Larmor Equation

Larmor Equation

- The Larmor equation states that the precessional frequency, w_0, is a product of the gyromagnetic ratio, γ, and the applied magnetic field, B0.

ω_0 = ***precessional frequency (MHz)***

γ = ***gyromagnetic ratio (MHz per T)***

B_0 = ***applied magnetic field (T)***

Gyromagnetic Ratio

- The gyromagnetic ratio relates the nuclear species own magnetism and the affect once exposed to a magnetic field.
- It is a constant and the precessional frequency of any nuclear species can be determined if the following are known:
  - the gyromagnetic ratio and
  - the strength of the magnetic field

Gyromagnetic Ratio

- The gyromagnetic ratio of hydrogen is:

  42.58 MHz per 1 T

- This is hydrogen's unique precessional frequency when under the influence of a 1 tesla magnetic field.

Larmor Equation

- Each MR instrument will have a characteristic Larmor frequency based on its static magnetic field strength.

w_0 = 42.58 MHz / T x 0.35 T = 14.903 MHz

w_0 = 42.58 MHz / T x 0.5 T = 21.29 MHz

w_0 = 42.58 MHz / T x 1.0 T = 42.58 MHz

w_0 = 42.58 MHz / T x 1.5 T = 63.87 MHz

W0 =42.58 MHz / T x 3.0 T = 127.8 MHz

Gyromagnetic Ratio

- Because the gyromagnetic ratio is a constant, the precessional frequency w_0, is directly proportional to the strength of the static magnetic field.

- W_0 / B_0

Larmor Equation

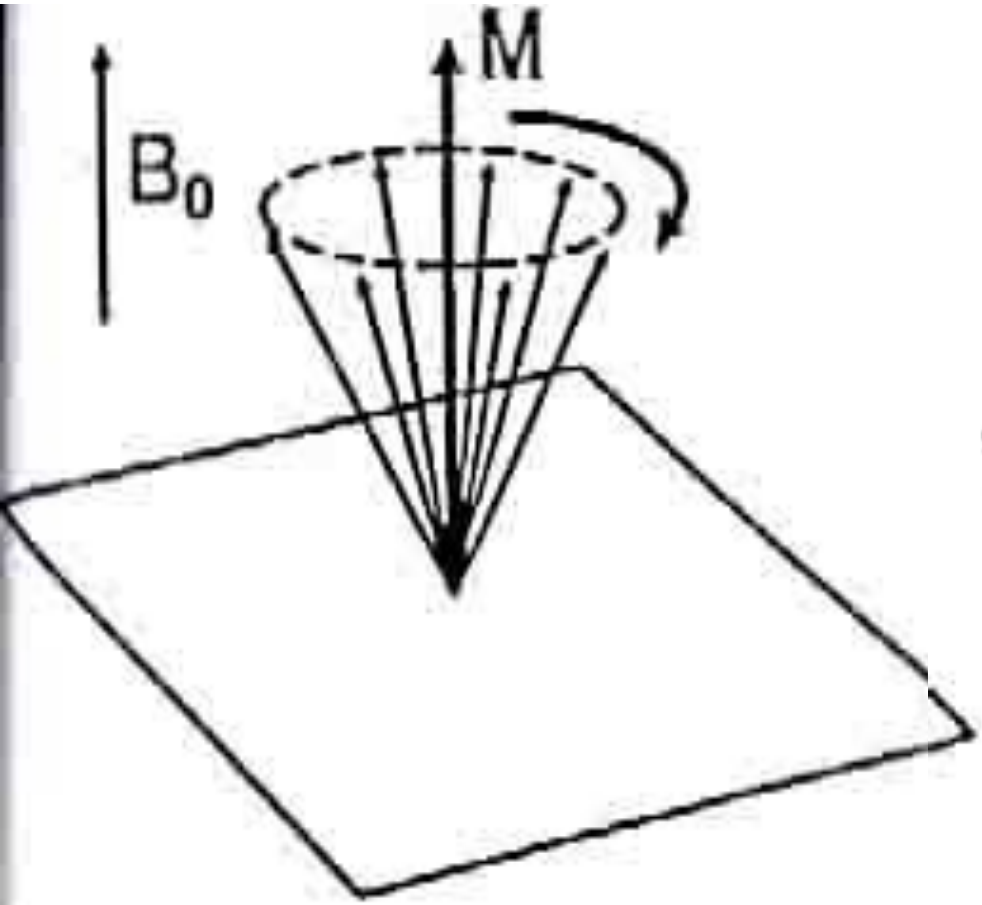
- The Larmor equation is the fundamental principle for the basis for spatial encoding of the NMR signal.

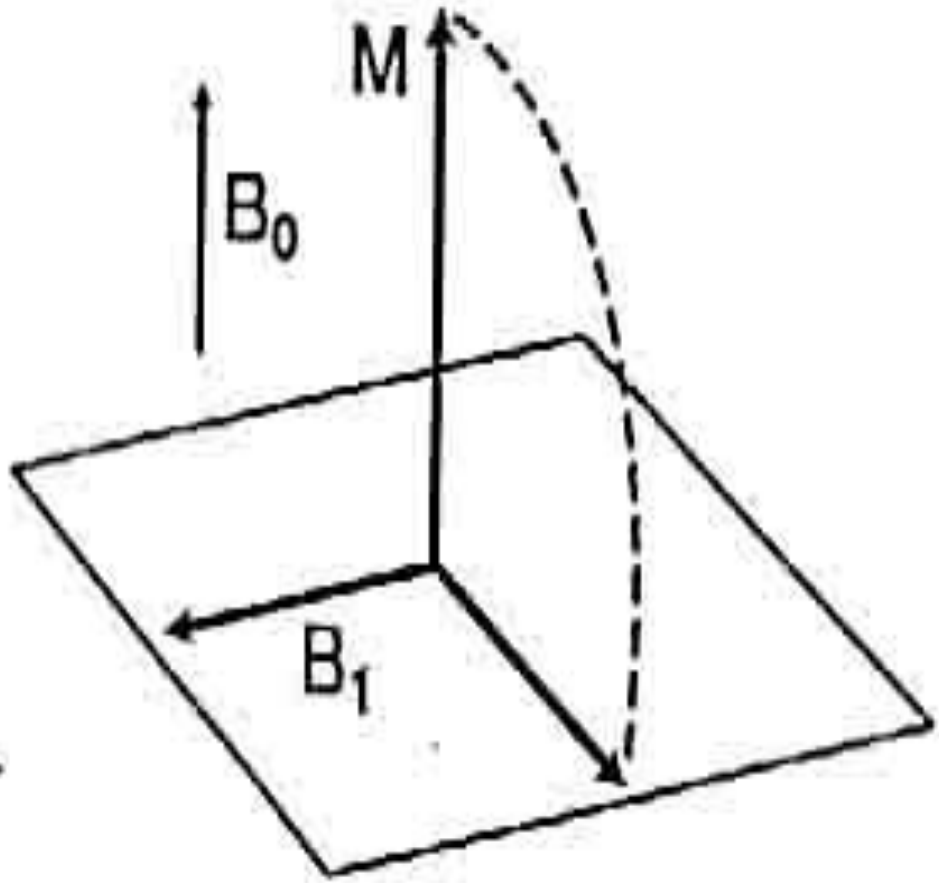
- Since the application of the gradient spatially varies the magnetic field, so does the precessional frequency of the hydrogen atom also vary.

Signal Production

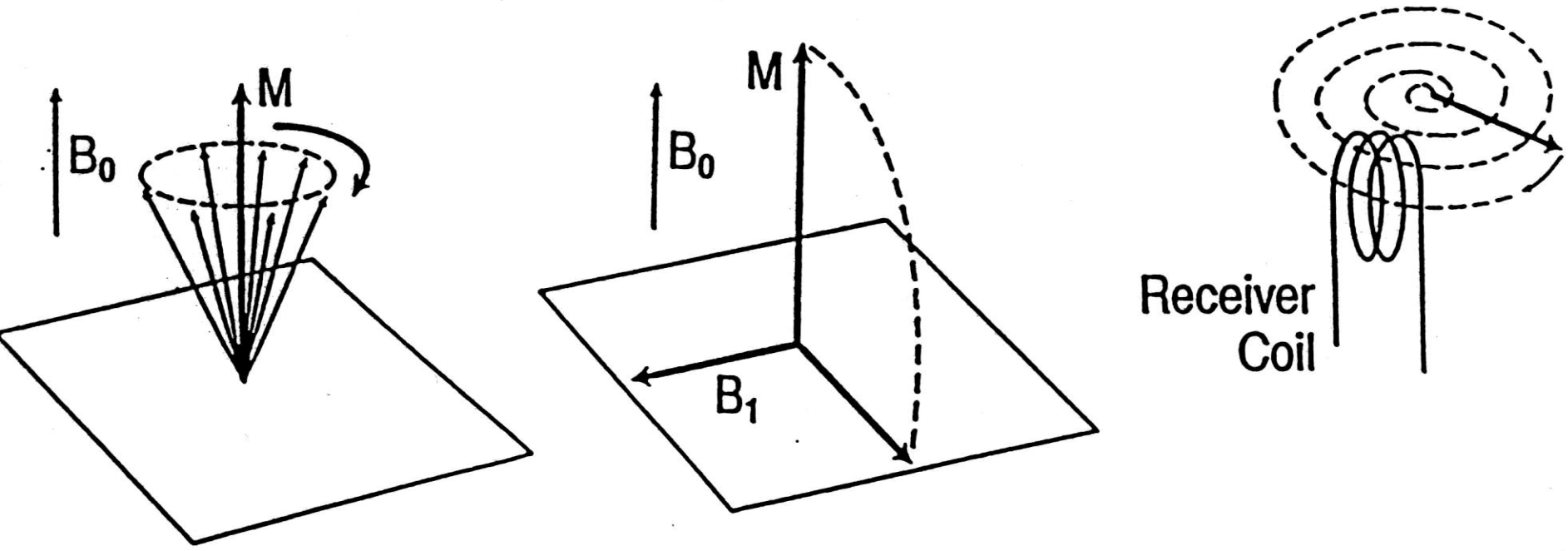
- To produce a signal, the net magnetic vector (M_0) must be moved out of the longitudinal plane into the transverse plane.
- This is where the radio frequency (RF) receiver coil is located to receive the signal.
- To do this requires the application of a secondary magnetic field (B_1), which will push net magnetization vector from longitudinal into the transverse plane.
- This secondary magnetic field is the RF pulse.

RADIOFREQUENCY PULSES





PRODUCING AN IMAGE = THREE BASIC STEPS



Signal Production

- It is also necessary to bring the protons into phase with one another (spinning together) by adding enough energy to the system to move some of the excess energy from the lower energy state into the higher energy state.

— quantum mechanics

Signal Production

- This is the same as moving the net magnetic vector into the transverse plane.

- To accomplish this, the secondary magnetic field, B_1, must be synchronized with the resonant frequency of the precessing atoms.

RF = PF

- The synchronized secondary magnetic field is an oscillating field that is the radio frequency (RF) pulse used to excite the atoms.

- When matching the RF to the resonant frequency of the atoms, w_0, resonance occurs!

RF same as PF causes resonance

Resonance

- Resonance is the absorption and re-emission of energy caused by the matching of the radio frequency to the precessional frequency of the atoms.

Resonance

- In order for resonance to occur the frequency of the oscillation must match the resonant frequency of the system.

- The RF pulse changes the direction of the net magnetization to the transverse plane.
  - This is necessary because only the transverse component of magnetization vector is detected by receiver RF coils.

Flip Angle

- The power amplitude and duration of the RF pulse determines the degree the net magnetic vector travels toward the transverse plane.
- This degree or angle is referred to as:
  - **flip angle**

Net Transverse Magnetization

- In addition to moving some of the spins to the higher energy level, the RF pulse also puts the spins into phase.
- This has the effect of moving net magnetization vector into the transverse plane.
- Only when the protons are precessing in phase (coherent) is it possible to detect the strongest signal within the RF receiver coil.

Pre-Scan by Pulse Sequence Controller

- **Shim magnetic field**
- **Tunes coil**
- **Set center frequency at iso-center**
- **Adjust transmit attenuation (RF Power Level)**
- **Adjust receiver attenuation (Receiver Gain)**

Failure to properly tune and match the coil may result in noisy images with poor contrast.

Conclusion

- These are the major principles involved in creating the NMR signal.

- Once the signal has been created, it must be collected and deciphered into a digital image.