Module 1: Nuclear Structure
Objectives

... Describe why the hydrogen atom is used in MR imaging
... Compute the summative effects of magnetic fields
g Vocabulary

• Atomic Number: the number of protons in the nucleus. This determines the type of element.

• Atomic weight: the number of protons and neutrons in the nucleus.

• Dipole: two magnetic poles of equal strength and opposite direction separated by a small distance.

• Magnetic moment: the product of the distance between magnetic poles and the strength of either pole.
Hydrogen Atom

- ELECTRON
- PROTON
- NUCLEUS

K SHELL
There are three characteristics of a subatomic particle: charge, mass, spin

• When pairs of neutrons and protons align, their spin values cancel.

• A nucleus with an odd number of protons and neutrons has a “left over” spin that does not cancel.

• This spin value plus the nuclear charge produce either a strong or absent magnetic moment.

• The nuclei that have a significant magnetic moment can be influenced by an external magnetic field and are therefore called MR Active.
Vectors

- A vector is a symbol representing the strength and direction of the magnetic field.

- Different magnitude, Same direction
- Same magnitude, Different direction
Net Magnetization Vector

The sum effect of all magnetic moments for a given sample

Represented by the symbol $M_z$
Vectors

**Magnetic fields have summative affect**

- When there is a concentration of north poles oriented in one direction, the magnetic field is stronger.
- When there is mix of north and south pole orientations, the magnetic field strength is weakened.
1. Moving charged particles create a magnetic field. What do we call this magnetic field?

2. What part of the atom are we concerned about in MR? The nucleus or the electrons?

3. What is one of the fundamental differences between MRI and x-ray?

4. What makes a nucleus MR active?

5. Look at the vectors and write the summative affect.
1. Why do we image H₁?
   - It is MR active (it has the greatest magnetic moment of all MR active elements)
   - It is very abundant in human bodies

2. Magnetic fields have summative effects

\[ \uparrow \uparrow = 0 \]

\[ \uparrow \downarrow = 0 \]
Module 2: Alignment & Precession
Alignment and precession

Objectives

...Describe effects magnetic field has on body

...Define why magnets at different field strengths have different protocols.
• $B_0$: the symbol used for the static magnetic field.
• Hertz: a standard unit of measurement for frequency, measured in cycles per second
• (1 hertz = 1 cycle per second)
• Phase: a position in time along a rotation
Random spin orientation
Spins in $B_0$ field

$B_0$
Spins in higher $B_0$ field
The greater the magnet field strength the greater the number of hydrogen protons that will align with the main magnetic field ($B_0$).
Net Magnetization

When the net magnetization vector is aligned with Bo, we label it $M_z$.

When the net magnetization is moved into the transverse plane, we label it $M_{xy}$. 
Precessional Frequency

- A spin or wobble that is caused by the static magnetic field.
- The protons spin or wobble in a circular path about $B_0$. 

Wobbling: Angular Momentum

Precessing: Magnetic Momentum
Precessional Frequency

It changes proportionally to $B_0$ changes

Lower $B_0$  Higher $B_0$
Larmor Equation

\[ \omega = \gamma B_0 \]

Precessional Frequency

HYDROGEN

(42.6mHz)

Magnet Field Strength
## Precessional Freq. Chart

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<th>Isotope</th>
<th>$\gamma$</th>
<th>mHz</th>
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<th>0.5</th>
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Progress Check

1. Larmor’s equation
2. Precessional frequency
3. Net magnetization vector
4. MR Active Nuclei
5. Magnetogyric ratio
6. Magnetogyric ratio for H1
7. Elements of an atom
8. Vector
9. $M_z$
10. $M_{xy}$
11. Hertz
12. Phase
13. Frequency
14. Magnetic moment
Progress Check

Scenario 1
Your radiologist has just returned from a conference and is excited about trying a new protocol for pituitary adenomas. Your MR system is a 1.5T magnet and the protocol he gives you is from a .5T magnet.
Can you use these protocols? Explain your answers.

Scenario 2
Your MR system is a .5T magnet. A new radiologist has joined the staff and has brought along the protocols from the 1.5T system she used to scan with.
Can you use these protocols? Explain your answers.
As $B_0$:
- the number of unpaired protons in the low energy state
- the precessional frequency

Larmor’s equation:
$$\omega = \gamma B_0$$
(42.6 mHz)
Module 3: Resonance
Objectives

...Describe what happens to nuclei and net magnetization vector when RF is applied.

...Diagram the transverse magnetization that occurs when flip angles vary.

...Estimate the SNR changes as flip angles vary.
• $B_1$: a magnetic field introduced perpendicular to the external magnetic field ($B_0$).

• In MR this magnetic field is produced by an electromagnetic wave at a particular radio frequency.
If the radio frequency equals the precessional frequency, then resonance occurs.
If the radio frequency equals the precessional frequency, then resonance occurs.
Radio Frequency

Frequency = number of crests or cycles per time period

Amplitude

Wavelength
Two conditions must be met before resonance can take place:

1. The RF must be introduced perpendicular to $B_0$.
2. The frequency of the RF must match the precessional frequency of the nuclei.
Resonance

When RF is applied nuclei absorb RF energy and shift from a low to a high energy state.
The amount of RF power used affects the amount of longitudinal magnetization moved to the transverse plane.

**RF**

EX. 90°
RF moves the protons to an in-phase state.

Protons precessing out-of-phase

Protons precessing in-phase
Progress Check

1. The RF is transmitted _________ to $B_0$.

2. What is the name of the equation that determines the frequency of the RF?

3. Describe what happens to the net magnetization vector when the RF matches the precessional frequency of the protons.

4. Describe what happens to the nuclei when the RF matches the precessional frequency of the protons.
5. If the RF = precessional frequency

\[ \text{If the RF = precessional frequency} \]

\[ \text{Then,} \]

- the nuclear energy state changes from low to high
- out of phase to in phase

6. Varied flip angles

\[ \text{Varied flip angles} \]

- Less SNR
- More SNR

\[ \text{RF} \]
Module 4: MR Signal Generation
Objectives

...Describe what happens to the nuclei and the net vector when RF is terminated.

...Identify three “human factors” that determine MR image contrast
Vocabulary

• FID: an abbreviation for Free Induction Decay which is the measurable MR signal that is induced in the receiver coil after the RF transmission is terminated.

• Free precession: the absence of a driving RF force.
Two phenomena occur when RF is terminated:
1. Nuclei emit energy and shift from a high to low energy state.
2. Magnetization returns to longitudinal plane.
Free Precession

As transverse magnetization decays, nuclei get out of phase with one another.

RF present

RF absent
T1 and T2 Happen Simultaneously
For signal to be generated, the RF released from the protons must pass across the receiver coil.
## Faraday's Law

1. Conductor must be present
2. Magnetic field must be present
3. Motion of magnetic field relative to conductor

## M R Signal

1. R F Coil (receiver)
2. Net Vector
1. What happens to the nuclei when the RF is terminated?

2. What happens to the net magnetization vector when the RF is terminated?

3. What law of physics explains the generation of the MR signal?

4. The RF coil receives signal in which plane?

5. Is any signal read when a vector is aligned with the longitudinal axis of the magnet?
Signal Generation

7. When the RF is stopped:
   
   T1: longitudinal regrowth (high - low energy)

   T2: transverse decay (nuclei dephase)

   Simultaneous

8. Signal

   No Signal