

GE Healthcare

# TiP-TV<sup>®</sup> Training in Partnership Program Supplement and Test for Imaging Professionals

## MR: A Physics Primer

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1.0 ASRT-approved Category A CE Credit



imagination at work

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## Program Summary

This page provides an overview of the program content and learning objectives. The Table of Contents provides a detailed list of the topics covered. Please keep a copy of this Program Summary and the Table of Contents with your continuing education certificate. It is also recommended that you provide a copy of this information to your manager as a record of your educational achievement.

### Program Description and Target Audience

"That's a penguin." In this program, one of the world's leading medical physicists correlates the relationship of penguins to understanding the concepts of electrostatics, electrodynamics, magnetism, electromagnetism, electromagnetic radiation, and contrast resolution. This program offers a fascinating perspective on the physics of magnetic resonance (MR).

The course objectives specifically target MR technologists.

### Program Objectives

By the end of this program, the viewer should be able to:

1. Describe the magnetic states of matter.
2. Discuss the magnetic properties of susceptibility and permeability.
3. Summarize the principles of magnetic induction.
4. Explain the importance of contrast resolution in magnetic resonance imaging (MRI).
5. Define Larmor frequency.

### Continuing Education Credit

1.0 ASRT-approved Category A CE Credit

**NOTE:** While the technical content is most effective for the target audience, other technologists and medical personnel may also benefit from viewing this course. Regardless of your imaging specialty, you may apply for continuing education credit. Refer to the Continuing Education Credit page for additional information.

## Continuing Education Credit and Video File Download (\*\*NEW\*\*)

### Online Process for CE Credit ([hls.gehealthcare.com](http://hls.gehealthcare.com))

In order to receive continuing education credit, you must log into the GE Healthcare Learning System (HLS) and complete all of the required steps. Please refer to the online TiP-TV Quick Start User Guide (click the User Guides link on the HLS Welcome page) for additional information on how to use the GE HLS as needed.

1. **View the entire program video** online or download the video file for later viewing (refer to the process below). This supplement is *not* intended to replace watching the video.
2. Go to the GE HLS web site at [hls.gehealthcare.com](http://hls.gehealthcare.com) and complete the **feedback form**.
  - ♦ NOTE: The Feedback Form link is not activated until the View Video Now module has been completed.
  - ♦ This provides valuable information regarding your thoughts on the program's quality and effectiveness.
3. Complete the **program post-test** without aids or assistance of any kind; this is an *individual effort*.
  - ♦ You have up to three attempts to successfully complete the test with a minimum passing score of 75% (ASRT-approved programs) or 80% (SNM-approved programs).
  - ♦ The post-test measures knowledge gained and/or provides a self-assessment on a specific topic.
4. Upon successful completion of the online CE information, you can instantly print a **certificate**.
5. Florida residents: The process for submitting CE credit to the FL DOH can be found online in the Related Documents tab on the bottom of the program's Item Details page.

### Video Download Process (\*\*NEW\*\*)

For programs with an original start date of September 1, 2008 or later, the GE HLS includes an option to download the TiP-TV program video file. You can then watch the program on your personal computer or transfer the video file to your portable video player for viewing.

**NOTE:** Please refer to the **TiP-TV Video Download Quick Start Guide** for complete details (click the User Guides link on the GE HLS Welcome page).

- With the desired program in your GE HLS Learning Plan, launch the program content to view the Online Content Structure. In the Video Download (Optional) area, click the Download Video to View Later link.
- Save the video file on your personal computer, using your existing video download software.
- View the program on your personal computer or transfer it to your portable video player for later viewing.
- After viewing the entire program, log into the HLS and complete the CE activities as noted above.

### Continuing Education Credit Eligibility — Important Notice!

A GE Healthcare TiP-TV course may be available in several different formats, such as an online web course or CD/DVD. You may only be able to receive CE credit once for a particular course, regardless of the format in which it was viewed. If you have already received credit for a course, you are encouraged to contact your CE certification organization (ARRT, NMTCB, ARDMS, etc.) to determine if you can repeat this course for CE credit.

Thank you for choosing GE Healthcare as your continuing education partner. We hope you will join us for other TiP-TV programs in the future. For more details and program schedule information, please visit our education web site ([www.gehealthcare.com/education](http://www.gehealthcare.com/education)).

Please forward any questions or comments to: [geeducation@ge.com](mailto:geeducation@ge.com)

## Introduction

In this TiP-TV program, one of the world's leading medical physicists, Dr. Stewart Bushong, Professor and Chief of the Section of Radiologic Science in the Department of Radiology at Baylor College of Medicine in Houston, Texas, explains the relationship of penguins to an understanding of the concepts of electrostatics, electrostatics, magnetism, electromagnetism, electromagnetic radiation, and contrast resolution.

**NOTE:** Please view the video portion of this program as Dr. Bushong explains how flightless waterfowl impact education.

In this program, Dr. Bushong:

- Reviews the underlying fundamentals of electricity, magnetism, and electromagnetism, as they relate to MRI.
- Describes the production of an MRI image as analogous to other electromagnetic induction devices (e.g., radio and television).
- Discusses the components of an MR image:
  - Parameters
  - Spin density
  - Relaxation times
  - Magnetic susceptibility
  - Chemical shift
- Explains the relationship between classical physics and quantum physics considerations for MRI.
- Describes the origin of the free induction decay (FID), spin echo (SE), and gradient echo (GE).
- Identifies image reconstruction techniques.

## A Penguin Tale

On the first page of Dr. Bushong's books (*Magnetic Resonance* and *Radiologic Science for Textbooks*), he relates an analogy borrowed from his colleague, Dr. Ben Archer. This is the penguin tale.

In the Antarctic, there is a beautiful iceberg that is so glorious that it attracts penguins from far and near. They climb on the iceberg until there are so many penguins that the iceberg becomes **saturated** with penguins. The iceberg cannot hold anymore, so the next penguin that climbs on, pushes a penguin off. The penguins are at **equilibrium**.

**Saturation** and **equilibrium** are physics words in MR imaging. In an educational analogy, that iceberg is your brain, and those penguins are facts. That's something that is really important, so stuff those penguins (facts) into your iceberg (your brain). You'll never know what you're pushing out the other side, but you have to put those facts there for the time being.

## Physical Principles

**NOTE:** Dr. Bushong presents a number of graphs and diagrams in the video segment of this program; these have not been reproduced in this supplement in order to maintain a manageable, downloadable file size. Full comprehension of the information may be dependant on Dr. Bushong's explanation and presentation style, therefore the video is referenced throughout this text.

## Electrostatics

**Electrostatics:** the branch of physics that deals with electric charges at rest, or static electricity.

Electrostatics is a basic principle involved with MRI and making an MR image. The turn of the 20th century was considered the golden age of physics. In addition to Wilhelm Roentgen's discovery of x-rays, physicists better described the details of an atom. Ernest Rutherford identified the nuclear atom and Niels Bohr described planetary electrons around the nuclear atom. Albert Einstein worked on general relativity, which has to do with the motion of those small particles; this was also described by Max Planck's theory of quantum mechanics. The compilation of the work of these pioneering scientists presented an understanding of modern day electrostatic concepts.

Electrostatics deals with resting electric charges, principally the electron. The unit of electrostatic charge is the Coulomb, defined as 10 to the 18th electrons. The number seems strange because the system for electrical measurement was established prior to the discovery of the electron. That's unimportant, although it is of some historical significance. The fact stands that if you have 10 to the 18th electrons, you have 1 Coulomb of electrostatic charge.

Electrons can be static, that is, at rest, or they can move. The opposite of the electron is the proton, which does not move. Protons are not a part of conduction. When an electron moves in a conductor, it consists of, and generates, electricity. A Coulomb of electrons moving down a conductor, passing a given point in one second, is an ampere.

#### Equation 1 Coulomb Definition

$$\begin{aligned} 1 \text{ Coulomb} &= 6.24 \times 10^{18} e^- \\ 1 \text{ Coulomb/second} &= 1 \text{ ampere} \end{aligned}$$

**NOTE:** Please watch Dr. Bushong's demonstration in the video portion of this program.

In the diagram, notice that the electron and the proton have arrows pointing in or out. Those arrows symbolize the electric field. Electrostatics behave under a field effect. An example of a field is gravity. Human bodies have mass, they weigh something. The earth has a large mass. Anything that has mass, has an associated gravitational field. In the case of gravity, it is attractive in nature.

Similar to gravity, electrostatic charges have electric fields. These electric fields, unlike gravity, can be attractive or repulsive, depending on the nature of the charge involved. In Equation 2, the electric field demonstrates force per unit of charge. The force is also proportional to the square of the distance from the charge. As radiologic technologists, you should be familiar with the inverse square law. The inverse square law also applies to electrostatic force. Electrodynamics concerns the movement of these electrons in a conductor. As stated in Equation 1, 1 Coulomb per second, equals 1 ampere.

#### Equation 2 Inverse Square Law

$$\vec{E} = \frac{\text{Force}}{\text{Charge}} \sim \frac{\text{Charge}}{\text{Distance}^2}$$

## Magnetism

A bar magnet is bipolar, meaning it has a north pole and a south pole. By convention, imaginary lines of the magnetic field exit the north pole and enter the south pole. Equation 3 calculates the intensity of the magnetic field in Newtons per ampere-meter (1 Newton per ampere-meter = 1 tesla [T]).

**Equation 3** Magnetic Field Intensity

$$\vec{B} = \frac{\text{force}}{\text{pole}} \left( \frac{\text{N}}{\text{Am}} \right)$$

B = field strength in tesla  
 Force is measured in Newtons  
 Pole strength is displayed in ampere-meters

There are three magnetic states of matter:

- **Ferromagnetic**
  - Are iron and iron-like substances that can generate a relatively strong magnetic field.
- **Paramagnetic**
  - Have a very weak magnetic field.
  - Gadolinium, for instance, is used as a contrast material because it is paramagnetic.
- **Diamagnetic**
  - Have no magnetic field.

The point to remember, is the degree of magnetization (ferromagnetization, paramagnetization, or diamagnetization) is dependent on the number of unpaired electrons in the outermost shells of these atoms. Iron has 10 unpaired electrons in the outer two shells and therefore can be rendered easily into a very strong magnet.

There are two other terms that a technologist should be familiar with regarding magnetism and magnetic properties:

- **Magnetic susceptibility** – the measure of how readily a material can be rendered into a magnet.
  - If iron is placed in an electromagnet, it becomes magnetized.
  - The influence of the electromagnet causes iron to become a strong permanent magnet.
- **Magnetic permeability** – how well a material attracts the imaginary lines of the magnetic field.

When an MR imaging system is installed in a room, iron is sometimes placed in the walls, because the iron is permeable and attracts the imaginary lines of the magnetic field. Therefore, the iron shielding does not allow the magnetic field to extend out into the adjacent corridor where patients with metal implants or pacemakers may be affected. When an MR imaging system is shielded with iron or other materials that have high magnetic permeability, it is similar to shielding an x-ray room with lead. Lead absorbs x-rays, iron absorbs magnetic fields.

## Electromagnetism

In approximately 1820, Hans Oersted accidentally noted that a compass was deflected by a direct current (DC). The Chinese demonstrated knowledge of compasses two millennia ago, and knew that a compass points north. They did not know that a compass points north because of an interaction between the magnetic permeability of iron and the magnetic field of the earth. Oersted showed that if you close a switch completing an electric circuit, the compass points toward or away from the conductor.

**NOTE:** Please view the illustration used in the video segment of this program, the copper wire.

When no current is flowing in the circuit, the compass points to the earth's North Pole. The next step in the experiment is to change the wires so the current is flowing in the opposite direction. When the current flows oppositely and you close the circuit, the compass now points 180 degrees from its original orientation. Oersted's experiment showed, for the first time, that there is a relationship between electricity and magnetism. This relationship is called electromagnetism and is the principle on which an MR imaging system is made.

Because of Oersted's discovery, it is known that an electron in motion generates a magnetic field. The magnetic field is concentric and perpendicular to the motion of the electron. If the electron moves in a circular path, it makes the magnetic fields fold back in on themselves as a toroid. This configuration is similar to the magnetic field in an MRI system. The circular path to move the electrons is provided by a coil of wire with current running through it. The imaginary lines of the magnetic field are generated around each coil of the wire. If a series of loops is formed from a current carrying wire, a more intense magnetic field is produced. Such a helically wound coil of wire is called a solenoid. The sum total of the magnetic field at the axis of the solenoid is termed  $B_0$ .

## Electromagnetic Induction

Between 1840 and 1850, Michael Faraday, an English monk, performed an electronic experiment. At the time, he knew that magnets were associated with both magnetism and electricity, but he did not know the exact relationship. He placed a bar magnet inside of a coil of wire. By moving the magnet back and forth through the center of the coil, he showed that a current could be produced (induced) in the wire. When the magnetic field is static, there is no motion imparted to the electrons in the wire. The motion of electrons is called electromotive force (EMF), more commonly known as voltage. Moving the magnetic fields are sometimes called transient magnetic fields; these are the magnetic transient fields that are used in the gradient magnets of an MRI system.

## Electromagnetic Radiation

The last relationship between electricity and magnetism is what happens when a moving electron is made to decelerate, change direction, or change motion. In an x-ray tube, that deceleration results in the production of an x-ray. The loss in velocity is transformed from Newtonian energy, the energy of motion, to electromagnetic energy, that of an x-ray. In radio electronics, which is what is used in MRI, that changing electron velocity results in the emission of a radio frequency (RF), commonly referred to as a radio wave.

**NOTE:** Please view the video portion of this program to see an illustration of a photon of electromagnetic radiation.

An electromagnetic photon consists of electric and magnetic fields oscillating at right angles to one another and traveling at the speed of light,  $3 \times 10^8$  meters per second. When the field disturbance (oscillation) is perpendicular to the direction of propagation, this is known as a transverse wave. The intensity of each photon begins at zero, increases rapidly to a maximum, and decreases to zero again. This process of increasing in intensity and then returning to zero is known as a cycle. One cycle passing a given point in the time of 1 second is 1 Hertz (Hz). The number of cycles that pass a point in 1 second is known as the frequency of the wave.

<p><b>Unit of frequency</b> 1 Hertz = 1 cycle/second</p>
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MRI uses radiation in the millions of cycles per second, or megahertz (MHz), range of the RF band. This is in the same range as radio and television broadcasts, so there can be some interference from commercial broadcasts. For MRI systems, the rooms are shielded from that kind of RF energy.

Heinrich Rudolf Hertz was a German physicist who clarified and expanded the electromagnetic theory of light that had been put forth by James Clerk Maxwell. He was the first to satisfactorily demonstrate the existence of electromagnetic waves by building an apparatus to produce and detect very high frequency (VHF) or ultra high frequency (UHF) radio waves. In his work he also discovered x-rays almost five years before Roentgen. Hertz and his associates dismissed x-radiation as an artifact until Roentgen published his work on the subject.

As previously discussed, a resting electric charge radiates an electric field. When the charge is in motion, a magnetic field is generated. This is the principle of radio, in which case electromagnetic radiation is called RF. Oscillating electrons in the transmitting antenna produce RF, which in turn induces a signal in the receiving antenna. The receiving antenna pays no attention to the oscillating electric field; however, it does detect the oscillating magnetic field by way of Faraday's electromagnetic induction. It induces oscillation in the electrons in the antenna and that produces a signal to the radio receiver, which is demodulated and turned into sound. The same thing happens with television and MR. In MR, an RF signal causes the patient to emit the magnetic portion of that RF signal, and then detects that alternating magnetism by way of Faraday's induction; this produces an MR signal.

## Contrast Resolution

Dr. Bushong begins his discussion of contrast resolution by reviewing some of the pioneering work in MRI done by Dr. Raymond Damadian, Founder of FONAR Corporation.

"In 1970, Raymond Damadian, M.D., made the discovery that is the basis for magnetic resonance (MR) scanning that there is a marked difference in relaxation times between normal and abnormal tissues of the same type, as well as between different types of normal tissues. This seminal discovery, which remains the basis for the making of every MRI image ever produced, is the foundation of the MRI industry. Dr. Damadian published his discovery in his milestone 1971 paper in the journal "Science" ("Science" 1971,171,1151) and filed the pioneer patent for the practical use of his discovery in 1972."

Why perform an MRI? The two main reasons are:

- The contrast resolution is far superior for MR than for any kind of x-ray imaging.
- It's non-ionizing and therefore non-hazardous.
  - There are some potential hazards – x-ray imaging has the potential to transform a normal cell into a malignant cell. MRI, and the energy fields of MR, cannot induce a cell to transform into malignancy.

**NOTE:** Please see the video segment of this program to appreciate Dr. Bushong's graphical representation and discussion of contrast resolution as it pertains to MR, computed tomography (CT), and conventional radiography.

## Comparing MRI to general x-ray and CT

When a plain radiograph of the chest is placed on a view box for interpretation, what can be seen? The image is gray and flat and shows little detail. A conventional tomogram or an angiogram can be done to improve image contrast. Compared to conventional radiography, CT imaging displays superior contrast resolution, the ability to image differences among low-contrast tissues. Contrast resolution allows visualization of soft tissue with similar characteristics such as liver-spleen or white matter-gray matter.

The spatial resolution of a CT image is worse than that of radiographic imaging because it's digital and limited by pixel size. Likewise, the spatial resolution of MRI is worse than that of radiography. However, the contrast resolution is better with MRI than with CT.

In x-ray imaging, the x-ray attenuation coefficient, designated with the letter Mu ( $\mu$ ), determines the differential x-ray absorption in body tissues. In turn, the x-ray attenuation coefficient depends on the energy of the x-ray beam and the atomic number of the tissue being imaged.

The basis for the MR image is different. It is a function of several intrinsic nuclear magnetic resonance (NMR) characteristics of the tissue being imaged. The three most important tissue characteristics are:

- Proton density (PD)
- Spin-lattice relaxation time (T1)
- Spin-spin relaxation time (T2)

Secondary characteristics include:

- Flow
- Magnetic susceptibility
- Paramagnetism
- Chemical shift

There are two principal parameters to select in the production of a radiographic image:

- Kilovolt peak (kVp)
- Milliampere-second (mAs).

By carefully selecting kVp and mAs, radiographers can optimize the contrast resolution of an image without compromising the spatial resolution.

There are many parameters to select in the production of an MR image. The time sequence of energizing RF emissions (RF pulses) and gradient magnetic fields determines the contrast resolution. The principal pulse sequences are:

- Partial saturation
- Inversion recovery
- Spin echo
- Gradient echo
- Echo planar

Each sequence has a large selection of timing patterns of the RF pulses and resolution for visualization of various anatomic and disease states.

Referring to an MR image of the brain, Dr. Bushong presents his first **penguin**: you can see that depending upon the pulse sequence that you engage, you can cause the cerebral spinal fluid (CSF) to appear bright or dark. Or you can make a mistake and choose the wrong pulse sequence timing and lose your contrast. The difference between NMR spectroscopy and MR imaging is the use of gradient magnetic fields.

**NOTE:** Please watch Dr. Bushong's presentation of the contrast detail curve.

Notes:

**Penguin:** What's the answer to this? Why does CT have superior contrast resolution? Answer: collimation.

## Dipoles

Unlike the situation that exists with electricity, there is no smallest unit of magnetism. Because each magnetic domain exists with two poles, a north pole and a south pole, it is commonly called a dipole. Unlike electric charge, a magnet cannot exist with a single pole, Dividing a magnet simply creates smaller magnets.

Some molecules are bipolar; that is, they have a north pole and a south pole. Subatomic particles such as protons have a north pole and a south pole as just described.

An ensemble of proton spins is commonly referred to in MRI. In the video presentation, each of a number of compasses represent a single proton in a patient that is to be imaged. Each one of these dipoles is a magnetic moment; that is, the tendency of the magnetic force to rotate the dipole. When you place a compass, that magnetic moment, the dipole, in the presence of an external magnetic field, it causes that compass to align with the external magnetic field. It does not align with the earth's magnetic field as it did normally on the outside.

To analyze the effect of the magnetic field, the force and direction of the dipoles is plotted on a three-dimensional (3-D) Cartesian coordinate system, x, y, and z. If you add them all up, they equal zero. Although it is common knowledge that, in principle, magnets and superconducting magnets, the  $B_0$  field, and therefore the z-axis, is horizontal, it's always presented vertically, mathematically when developing relaxation curves.

When you place a patient, or in the case on the video, a possum, in an external magnetic field, something different happens. Classically, all the nuclei should precess about the applied field and the net magnet moment should remain zero.

Quantum mechanics predicts that more nuclei will exist in one state rather than in another. This nuclear alignment does not occur instantly, but rather over a period of time determined by the molecular nature of the tissue of the possum. Some tissues align quickly and others more slowly. One result of this alignment is that the net magnetization will not be zero.

The external magnetic field provides a small preference for the spins to align with the field. This is a small force compared with normal thermal interactions, and only a small number of spins align with the external magnetic field. The result can be illustrated as the vector described by Dr. Bushong, which shows that net magnetization exists along the z-axis, parallel to the external field.

If the possum is left in the magnet for a sufficient length of time, the number of spins oriented with the field stabilizes to an equilibrium value. The value is referred to as  $M_0$ , or the net magnetization at equilibrium, and is the largest possible value of  $M$ .

By convention, the external magnetic field is parallel to the z-axis of the Cartesian coordinate system; therefore, this magnetization can also be referred to as  $M_z$ , or the z component of the net magnetization. At equilibrium the x and y components of the net magnetization are zero, so  $M_x = M_y = 0$ , because all of the equilibrium magnetization is along the z-axis.

## Precession

In addition to polarization, another phenomenon occurs when a patient is placed in a static magnetic field. The phenomenon can be understood by considering a spinning top or gyroscope. If the gyroscope is taken into space and spins, it only spins. However, if the gyroscope spins on earth in the presence of a gravitational field, not only will the gyroscope spin, but it will wobble. Physicists call this wobble precession.

**Precession:** the interaction between the spinning mass of the gyroscope and the mass of the earth that is manifest through the gravitational field.

By spinning, the gyroscope creates angular momentum, which interacts with the angular momentum of the spinning earth and causes the precessional motion. Similarly, if a spinning magnetic field, such as the magnetic moment of the proton, is in the presence of a static magnetic field, it will also precess.

## The Larmor Equation

### Equation 4 Larmor Equation

$$\omega = \gamma B_0$$

**NOTE:** In Equation 4,  $\omega$  is the lower case symbol for omega in the Greek alphabet; it is used to represent frequency. Some texts use  $f$  to represent this term in the Larmor equation.  $\gamma$ - gamma represents the gyromagnetic ratio.

Equation 4 is the only equation you must know to understand MR imaging; it's called the Larmor equation. It states that omega, the frequency of precession, is directly related to the strength of the external magnetic field,  $B$ , by something called the gyromagnetic ratio. Gyromagnetic ratio is fixed for every element. The nucleus of every element precesses with a different gyromagnetic ratio, which is defined in units of MHz per T.

For instance, if you put a patient in a 1T magnet, the gyromagnetic ratio is 42 MHz per T for hydrogen. The operational frequency for a 1T magnet is 42 MHz. If you operate at any other frequency, there will be no image, no signal; it does not work. Table 1 presents the gyromagnetic ratios for some other elements used for imaging, none as successful as hydrogen.

Table 1 Gyromagnetic Ratios

Atomic Mass and Element	Percentage	Gyromagnetic Ratio (MHz T <sup>-1</sup> )	Relative Sensitivity
<sup>1</sup> H	99.9	42	100
<sup>19</sup> F	< 1	40	< 1
<sup>3</sup> P	100	17	7
<sup>23</sup> Na	3.2	11	12

Hydrogen is particularly successful because of its high gyromagnetic ratio frequency and the relative sensitivity compared to these other things. This is because there is essentially 100% hydrogen in the body. Compared with other nuclei in the body, hydrogen is the best for producing an MR signal.

### Harmonic Resonance

If you pluck a string of a guitar and a harp is standing nearby, one of the strings on the harp will begin to vibrate. 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.

### MR Imaging Characteristics

There are the three MR imaging system characteristics that you must know: T1 relaxation, T2 relaxation, and proton density. They are also referred with other names (see below).

- **T1 relaxation**
  - Longitudinal relaxation, because it is relaxation along the B<sub>0</sub> axis and in most cases is in the longitudinal plane of the patient as well.
  - Spin lattice relaxation, because it has to do with the manner in which each individual proton spin interacts with its molecular lattice.
- **T2 relaxation**
  - Spin-spin, due to interaction.
  - Transverse relaxation, its relaxation is transverse to the external magnetic field, in the x-y plane, rather than along the z-axis.
- **Proton density**
  - Spin density

Here is another **penguin**:

If you go from a 1.5T to a 3T magnet, you double B<sub>0</sub>. The intensity of M<sub>z</sub> also doubles; therefore, M<sub>0</sub> net magnetization at equilibrium. This increases the amount of signal and thus increases contrast and detail. The increase in contrast and detail is the goal of developing higher intensity imaging magnets. There's one problem with this: as field strength increases, penetration of the RF signal decreases. Techniques to use pulsed RF going into the patient and receive RF coming out of the patient are being developed to compensate for the penetration shortfalls.

## Equilibrium magnetization

If you put a patient in the magnet and the magnetization of the patient grows, and grows, and grows according to T1 relaxation time until he/she is at equilibrium, this is called equilibrium magnetization. It is illustrated with a vector, an arrow pointing up along the z-axis. Now, if you turn on an RF pulse tuned to 63 MHz, the individual spins are precessing, but they're precessing out of phase. If you turn on a radio pulse at 63 MHz, it causes all of the spins to precess in phase. At the same time it causes some of these spins to invert, to obtain energy and invert to the negative z-axis. If you leave the RF pulse on just a little bit longer, it will cause the net magnetization to rotate 90 degrees; this is called a 90° pulse (shown in the video illustration).

The z magnetization is now zero, but you have caused the spins to come into phase and therefore phase coherence; therefore, a signal is received. If you keep the RF pulse on for twice as long, you'll cause more spins to flip and you'll end up with magnetization not only on the z-axis, but at the negative z-axis; that's called an inverted pulse or 180° pulse.

In Fourier acquired steady state (FAST) imaging, the RF pulse is turned on for a little longer; that little length of time is termed an alpha pulse. It does not have long to recover back to equilibrium. This is one of the basic characteristics of FAST imaging, gradient echo imaging (GEI), and echo planar imaging (EPI). But even with an alpha pulse, you can generate magnetization in the x-y plane.

## Reference Frames

The concept of a frame of reference is necessary to follow the motions of the individual nuclear magnetic moments and the net magnetization vector. One convention within this system is that the applied magnetic field is always parallel to the z-axis. Although the z-axis is always drawn as up, its actual orientation is determined by the direction of  $B_0$  in the particular magnet system.

## Stationary Frame

The view of someone standing next to the magnet is referred to as the stationary frame of reference, because all motions are compared with a person standing still in the imaging room.

A second magnetic field with special properties must be used to flip the net magnetization off the z-axis. The second magnetic field must precess about the  $B_0$  magnetic field with the same frequency as the nuclei, which is the Larmor frequency. If it does not precess at the Larmor frequency, no interaction between the second magnetic field and the nuclear spins is produced. This phenomenon is called resonance, because it is a requirement that the second magnetic field must precess at exactly the correct frequency or nothing will happen to the net magnetization vector.

An electromagnetic emission, such as a RF, is composed of an oscillating electric field positioned 90° to an oscillating magnetic field.

The magnetic field component of an RF emission at the Larmor frequency is effectively a magnetic field rotating at the Larmor frequency. The precessing nuclear magnetic moments interact with the magnetic field component of the RF. Thus, through irradiation of the sample with an RF emission, a rotating magnetic field is produced to flip the net magnetization vector into the x-y plane.

## Rotating Frame

Because the net magnetization is precessing so fast, 63 MHz, visualizing its motion is difficult. A trick is used to make it easy to follow the motion of the net magnetization. An example of this can be found in an amusement park.

If someone is in line to go on a carousel and a friend is already on the carousel, it presents the same problem as the precession of the net magnetization in the stationary frame of reference. The rotation of the friend on the carousel relative to the person on the ground makes it difficult to carry on a conversation. However, if the person steps onto the carousel, the friends are now stationary relative to each other and they can converse easily. The rest of the world is rotating "backwards" relative to them.

The solution is to use a frame of reference that exactly matches the motion of the net magnetization. This is a reference frame precessing about the z-axis. This new frame of reference is called the rotating frame.

## Free Induction Decay

Assume a patient is in the magnet and there is an RF coil that transmits radio frequency into the patient at 63 MHz, as is the case with a 1.5T magnet. When the RF is transmitted into the patient instantaneously, two things happen:

1. **Some of these spins go from being aligned with the external magnetic field to being aligned against the magnetic field.**

Depending on how long the RF pulse is (how long it remains on), determines how much of the net magnetization along the z-axis goes into the negative position. With a  $90^\circ$  pulse, there will be as many spins below the axis as above; therefore, z magnetization will be zero.

2. **All of these spins are brought into phase coherence.** They all precess with the same frequency of 63 MHz.

You cannot measure the z magnetization; it's too small in the presence of the 1.5T external magnetic field. But when you rotate the magnetization onto the x-y plane and generate  $M_{xy}$ , then the vector rotates in the x-y plane and the radio receiving antenna (the coil around the patient) does not see the rotating magnetization. However, it sees a magnetic field approaching, receding, approaching, receding, approaching, receding, and that generates, by electromagnetic induction, a signal in the receiving antenna.

After that pulse, the oscillating magnetic field is received by the antenna, as two things happen at the same time. Very slowly, spins that were inverted are flipped back to the equilibrium position. Magnetization grows along the z-axis. At the same time, these spins that were placed into phase coherence interact with each other and come out of phase. When they come out of phase, there is no signal left, but while they're in phase, the magnetic field that they generate is viewed as an oscillating magnetic field by the receiving antenna. This rotating vector interacts with the receiving coil and as it interacts, the vector which is now the  $M_{xy}$  vector, gets smaller and smaller in amplitude because of dephasing, spin-spin interaction, or T2 relaxation.

This process is called free induction decay, or more commonly an FID. Immediately after a  $90^\circ$  pulse, this phase coherence in the x-y plane oscillates as it dephases. The signal intensity diminishes until the spins are totally dephased and there's no signal left; this is called a free induction delay. The dipole moments of the proton start out in phase in the x-y plane, and dephase.

## Appendix A: Presenters

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## Appendix B: Resources

### MR Glossary of Terms and Acronyms

A standard glossary of MR terms and acronym definitions can be found on the GE Healthcare Learning System (HLS) web site at [hls.gehealthcare.com](http://hls.gehealthcare.com). Click on the program title (in your Learning Plan or course catalog) to display the Items Details page. Open the Related Document tab and click the MR Glossary link.

### Reference

*Magnetic Resonance Imaging, Physical and Biological Principles*, Stewart C. Bushong, Mosby, Inc., St. Louis Missouri, 2003.

### Electronic Resources

American College of Radiology: <http://www.acr.org>

American Society of Radiologic Technologists: <http://www.asrt.org>

Institute for Magnetic Resonance Safety, Education, and Research: <http://www.IMRSER.org>

Medcyclopaedia: <http://www.medcyclopaedia.com>

MRIsafety.com: <http://www.mrisafety.com/>

MR Technologist's Corner:

[http://gecommunity.gehealthcare.com/geCommunity//interest\\_groups/tc\\_faulkner/tc\\_faulkner.jsp](http://gecommunity.gehealthcare.com/geCommunity//interest_groups/tc_faulkner/tc_faulkner.jsp)

National Institutes of Health: <http://www.nih.gov>

Radiological Society of North America: <http://www.rsna.org>

Section for Magnetic Resonance Technologists: <http://www.ismrm.org/smrt/>

**NOTE:** The Internet is an ever-evolving environment and links are subject to change without notice.

## Appendix C: Post-Test

LMS Course Number: 3399

To be eligible for CE credit, you MUST view the video presentation first. Then complete the post-test on the GE Healthcare Learning System ([hls.gehealthcare.com](https://hls.gehealthcare.com)) by the due date listed online.

1. Electrostatics deals with \_\_\_\_\_.
  - a. The  $B_0$  field
  - b. resting electric charges
  - c. proton density
  - d. contrast resolution
2. The unit of electrostatic charge is the \_\_\_\_\_.
  - a. ampere
  - b. volt
  - c. Coulomb
  - d. Mu
3. Electrodynamics concerns the movement of electrons in a \_\_\_\_\_.
  - a. static field
  - b. planetary orbit
  - c. Torrid
  - d. conductor
4. A body that has a north pole and a south pole is said to be \_\_\_\_\_.
  - a. bipolar
  - b. unipole
  - c. attractive
  - d. repulsive
5. Definition: 1 Newton per ampere-meter equals 1 \_\_\_\_\_.
  - a. ampere
  - b. tesla
  - c. dipole
  - d. volt
6. There are \_\_\_\_\_ magnetic states of matter.
  - a. one
  - b. two
  - c. three
  - d. four
7. \_\_\_\_\_ materials have no magnetic field and cannot be made to be magnetic.
  - a. Paramagnetic
  - b. Ferromagnetic
  - c. Pseudomagnetic
  - d. Diamagnetic

8. The magnetic state of matter of any material is dependent on the number of \_\_\_\_\_ electrons in the \_\_\_\_\_ shells of their atoms.
  - a. unpaired; outermost
  - b. unpaired; innermost
  - c. paired; outermost
  - d. paired; innermost
9. \_\_\_\_\_ is the measure of how readily a material can be rendered into a magnet.
  - a. Paramagnetism
  - b. Susceptibility
  - c. Permeability
  - d. Ferromagnetism
10. The term \_\_\_\_\_ indicates how well a material can attract the imaginary lines of the magnetic field.
  - a. Paramagnetism
  - b. Susceptibility
  - c. Permeability
  - d. Ferromagnetism
11. \_\_\_\_\_ showed, for the first time, that there is a relationship between electricity and magnetism.
  - a. Planck
  - b. Ohm
  - c. Volta
  - d. Oersted
12. The motion of electrons is called electromotive force; more commonly known as \_\_\_\_\_.
  - a. voltage
  - b. amperage
  - c. resistance
  - d. magnetism
13. The unit that denotes frequency is the \_\_\_\_\_.
  - a. ampere
  - b. Hertz
  - c. farad
  - d. ohm
14. \_\_\_\_\_ resolution is the ability to image differences among low-contrast tissues.
  - a. Spatial
  - b. Frequency
  - c. Contrast
  - d. Long-scale
15. The intrinsic tissue characteristics that are considered most important in MR imaging include all of the following, EXCEPT \_\_\_\_\_.
  - a. T1 relaxation time
  - b. spin-spin relaxation time
  - c. proton density relaxation time
  - d. magnetic susceptibility

16. Why does CT have superior contrast resolution?
  - a. Collimation
  - b. High kVp
  - c. Short acquisition time
  - d. Finite pixel size
17. The Larmor equation states that the frequency of \_\_\_\_\_ is directly related to the strength of the external magnetic field, B, by the gyromagnetic ratio.
  - a. the RF pulse
  - b. precession
  - c. the returning echo
  - d. dipole
18. If you go from a 1.5T to a 3T magnet, B sub zero\_\_\_\_\_.
  - a. is cut in half
  - b. remains constant
  - c. doubles
  - d. triples
19. The RF pulse transmitted into the body must be at the \_\_\_\_\_ frequency of the precessing hydrogen nuclei for energy to be transferred and imaging to occur.
  - a. reciprocal
  - b. received
  - c. transmit
  - d. resonant
20. When the dipole moments of the proton start out in phase in the x-y plane, then dephase, this process is known as \_\_\_\_\_.
  - a. free induction decay
  - b. harmonic resonance
  - c. magnetic induction
  - d. phase coherence