PHYSICS PRESENTATION

Topic: Working Principle of MRI

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What is MRI?

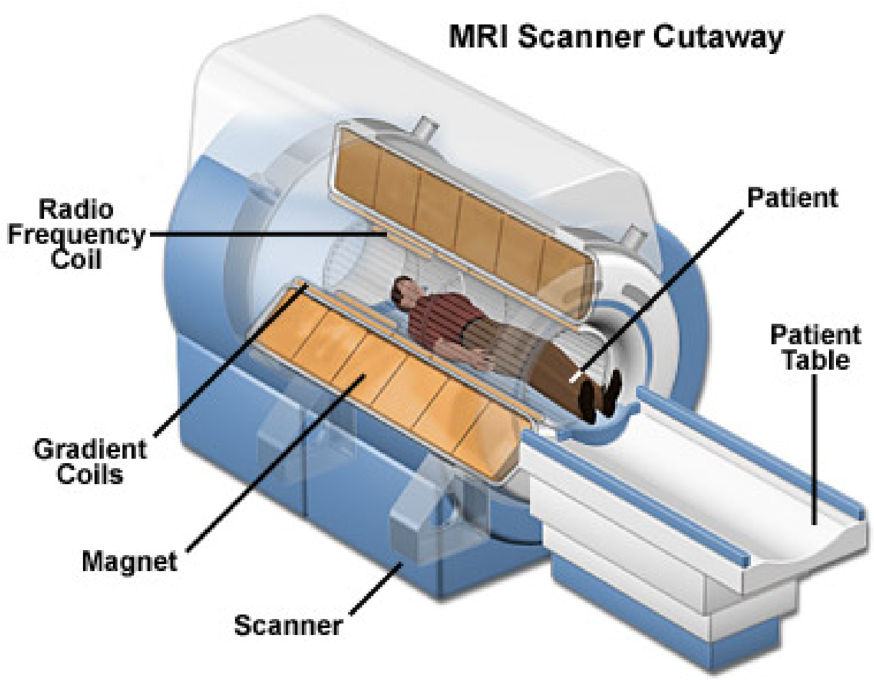
Magnetic Resonance Imaging (MRI) is a common, non-invasive imaging technique used in radiology. This technique uses strong magnetic fields, magnetic field gradients and radio waves to produce detailed anatomical images of the soft organs and tissues within our body.

MRI doesn't involve X-rays or ionising radiations, which distinguishes it from CT and PET scans. MRI is often used in the medical field for disease detection, diagnosis and treatment monitoring.

Components of MRI

A tube-like structure, known as the bore, holds the following components of the MRI machine-

Magnet, Gradient coils, Radio Frequency (RF) coil, Patient table, Antenna/ Computer system

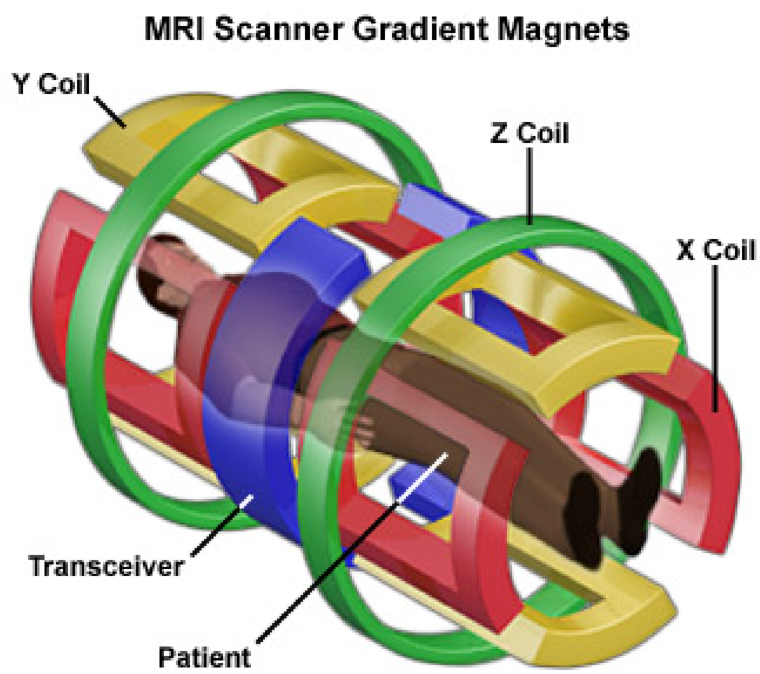


Magnet

The magnet is the biggest and most important component of the MRI device. The magnets are extremely strong and use a magnetic field in the range of 0.5-3 Tesla. This strong magnetic field is produced by passing a current through multiple coils (having zero resistance- by enveloping in liquid helium) that are inside the magnet. This results in a state of superconductivity, which produces a lot of energy.

Gradient Coils

A gradient is just a change in field strength from one point to another within the patient's body. There are three gradient coils that are located within the main magnet. Each one of these produces three different, relatively weaker magnetic fields. The gradient coils create a variable field (x, y, z) that can be increased or decreased to allow specific and different parts of the body to be scanned.



Radio Frequency (RF) Coils

The basic function of the RF coils is to transmit and receive radio wave signals from the patient's body. The RF energy used is a form of non-ionizing radiation.

Patient Table

This component simply slides the patient into the MRI machine. The position in which the patient lies down on the table is determined by the part of the body that has to be scanned. Once the part of the body under examination is in the exact centre of the magnetic field, which is referred to as the isocenter, the scanning process is initiated

Antenna/ Computer Systems

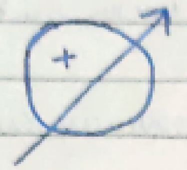
The antenna is a very sensitive device that detects the RF signals emitted by the patient's body and feeds this information into the computer system. The computer system is a powerful system, whose major function is to receive, record, and analyse the scanned images of the patient's body. It interprets the data sent in by the antenna and then produces an understandable image of the body part.

Working principle of MRI

Human body is mostly (70%) water. Water molecules (H2O) contain hydrogen nuclei (protons) which can align when subjected to a magnetic field. An MRI scanner applies a very strong magnetic field (0.5-3 Tesla) in order to align the net dipole moments of the protons (proton spins produce a spin angular momentum, which creates a net dipole moment).

The magnetic field applied is along the direction of the patient's body, i.e the z direction. Hence, the net dipole moments of the protons are all aligned along the z-axis.

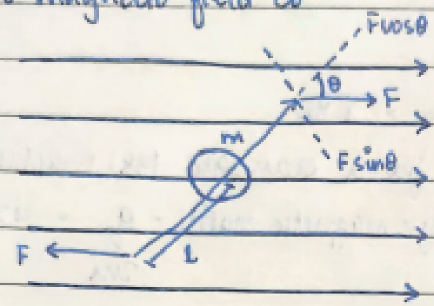
MAGNETIC PART



Dipole moment due to spin angular momentum (μ_p)

$$\mu_p = 1.41 \times 10^{-26}\ J.T^{-1}$$

Now, in external magnetic field B_0



where, F is the force on the dipole due to field B_0
m is the magnetic pole strength

We know that $F = m.B_0$

But ∵ forces apply in opposite direction, they cancel each other out

So, $F_{net} = 0$

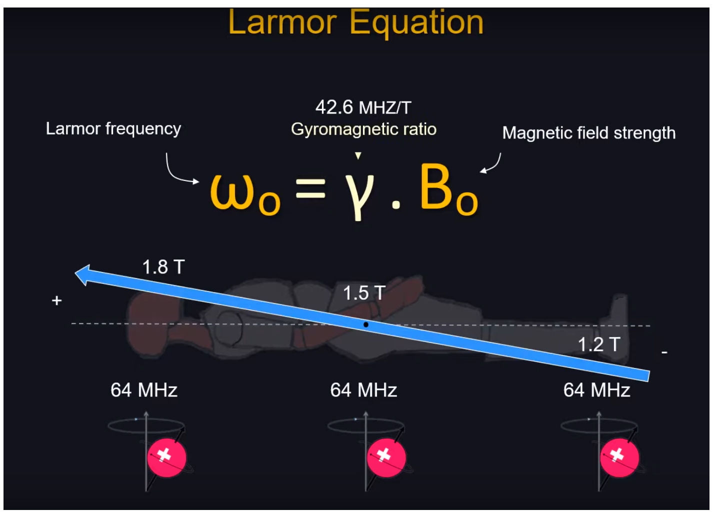
For torque (τ)

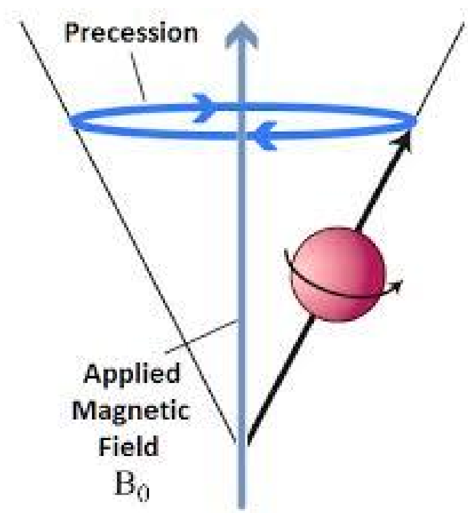
$$\tau = \text{Force} \times \text{Perpendicular distance}$$
$$= (m.B_0)\sin\theta \times 2L$$
$$= MB\sin\theta \longrightarrow (\because M = m.2L)$$
$$\tau = M \times B$$

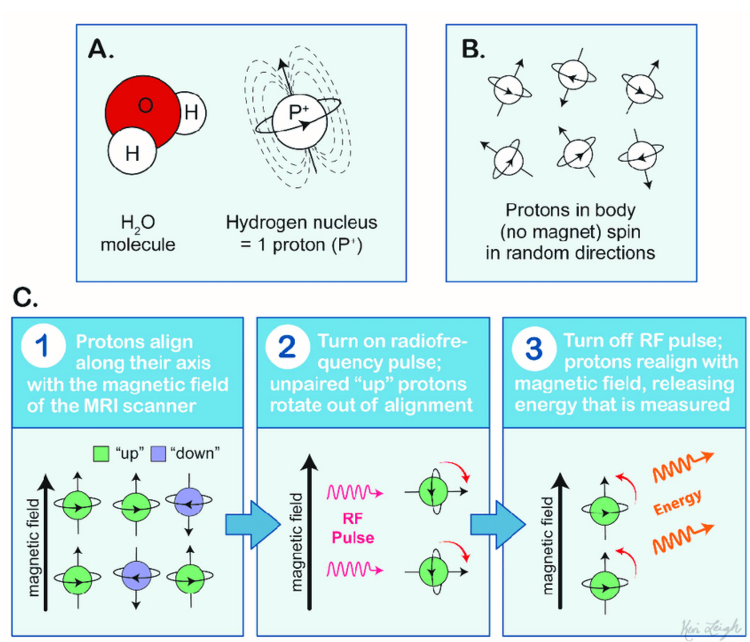
The above equation tells us that the proton dipole experiences a net torque in the direction of the magnetic field and aligns itself to the field.

The gradient coils produce additional, weaker magnetic fields in the x and y directions. This helps in creating a gradient (change in field strength) across the patient's body. Thus, protons in different parts of the body experience a different magnetic field strength.

The rotating protons undergo a process called precession (change in orientation of the rotational axis of a rotating body). The frequency at which these protons spin is known as the precession frequency or larmor frequency. The precession frequency has a linear dependence with the magnetic field. Since there is a gradient of magnetic field strength across the human body, the precession frequency of protons is different for different locations in the body







The RF coils produce a radio wave having the same frequency as the precession frequency of the protons (depending on the body part that has to be scanned). This creates a varying magnetic field The protons absorb energy from the magnetic field and flip the orientation of their spins by 90° (i.e. from the z-axis to either the x-axis or y-axis).

When the field is turned off, the protons gradually return to their normal orientation (z-axis). The return process produces a radio signal that can be measured by receivers in the scanner and made into an image.

RESONANCE PART

In order to change the orientation from z axis to x axis we bombarded the proton with radio frequency (RF) waves

Now, for near-complete energy transfer the radio frequency should be in resonance with the precession / larmor frequency

From larmor equation,

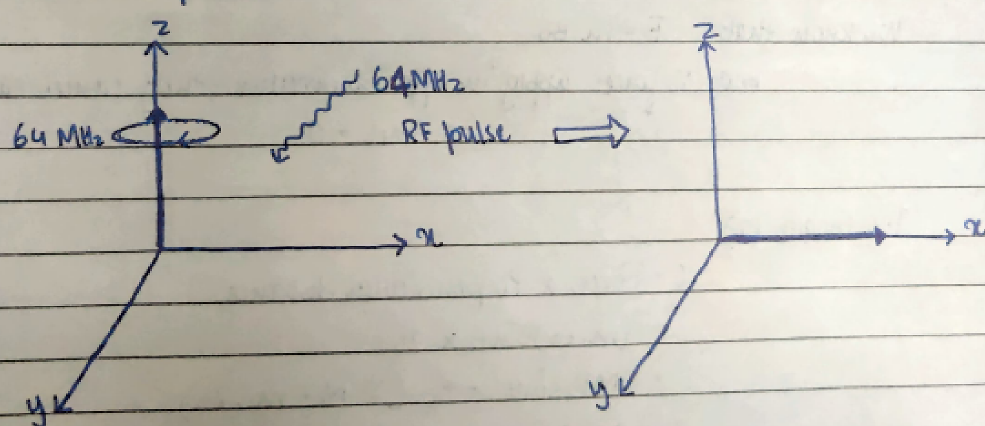
$$w_0 = \gamma B_0$$

Assume B_0 for a standard MRI machine = 1.5T

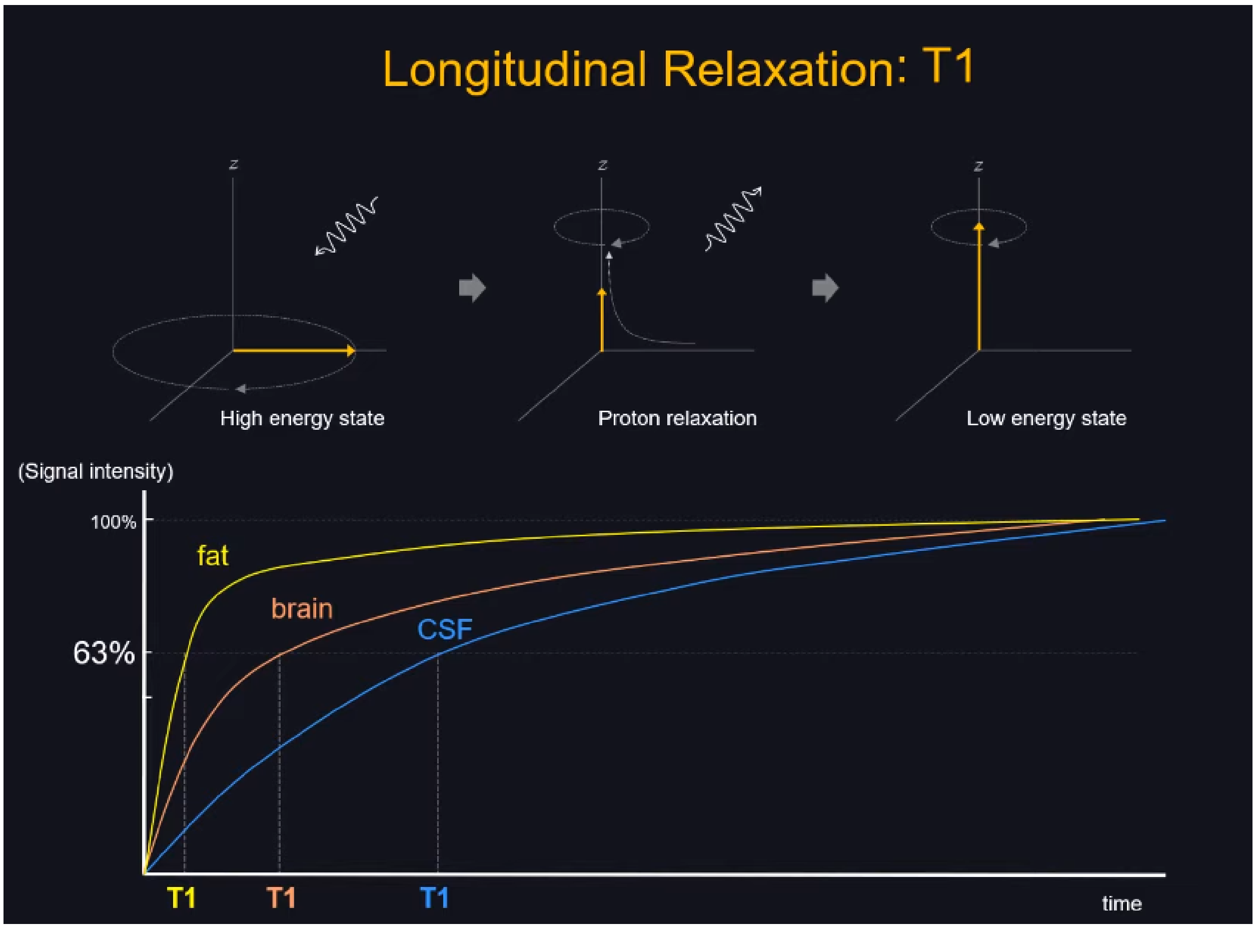
γ = Gyromagnetic ratio = $\frac{q}{2m}$ = 42.6 MHz/T

$\therefore w_0 = 1.5 \times 42.6 = 64$ MHz

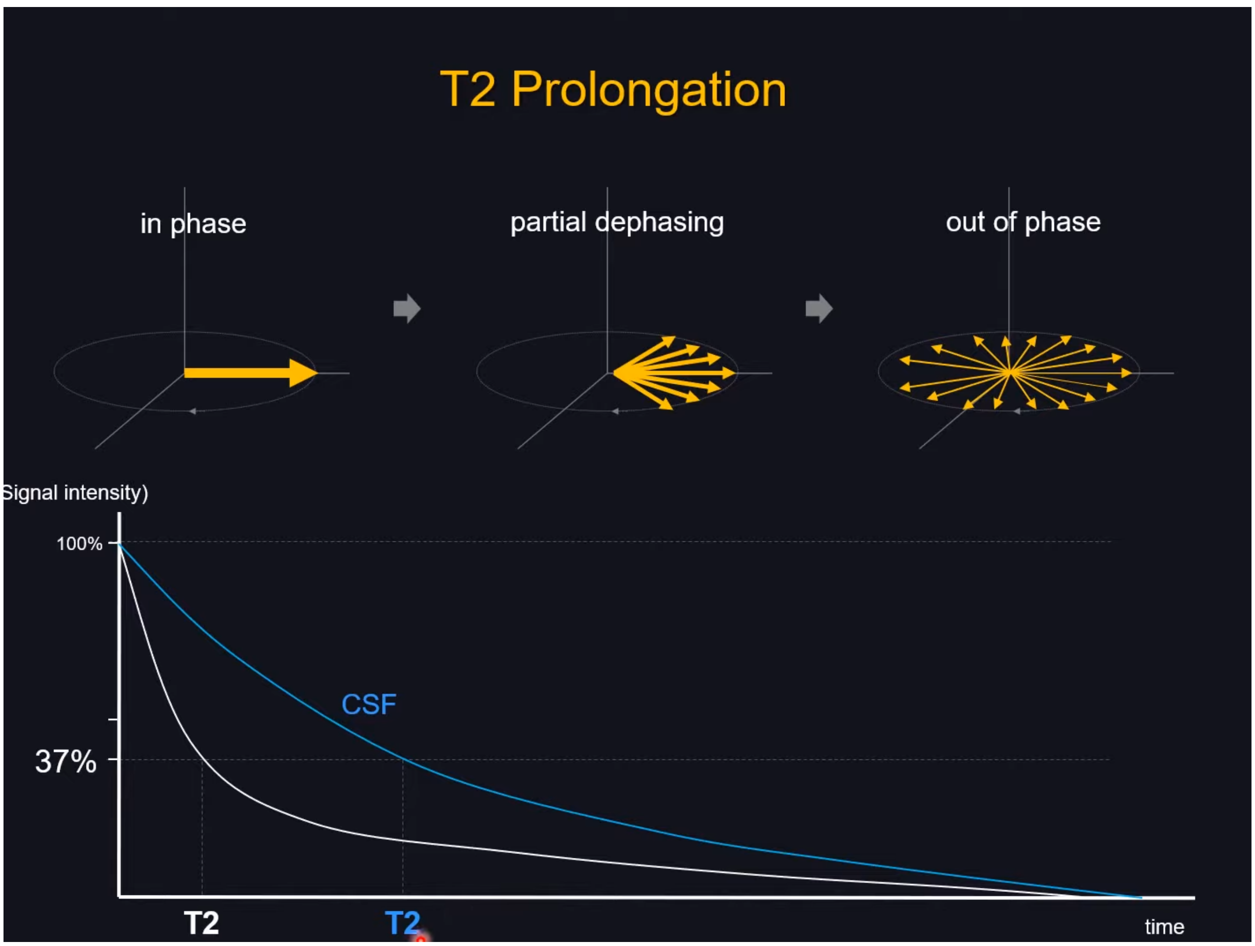
This frequency lies in the radiowave bandwidth and hence RF wave of 64 MHz is used to excite the protons



The time taken for the protons to return to their normal orientation is termed as t1 relaxation time. This relaxation time depends on the number of protons in a particular tissue sample (i.e. the water content of a sample). Hence, the graph of t1 is different for different tissues.This helps the scanner to distinguish between various tissues.



When the orientation of the protons is changed from the z-axis to the x-axis, the proton starts rotating in a circle on the x-y plane. Similarly, multiple protons form similar circles. Initially, all of the protons are in phase, but gradually they go out of phase. One of the possible reasons for this is spin-spin interactions.
Since all protons are having the same frequency, they start to resonate with each other and transfer energy to their neighbours. The first proton receives slightly more energy from its neighbour and thus has a slightly higher frequency than the rest. Similarly, the last proton gives out more energy to its neighbour and thus has a slightly lower frequency. This is why the protons go out of phase.
T2 refers to the time it takes for 63% of the protons to go out of phase of the time it takes for 37% of the protons to remain in phase.



These T1 and T2 interactions provide us with necessary signals to form the required images for the MRI scan.