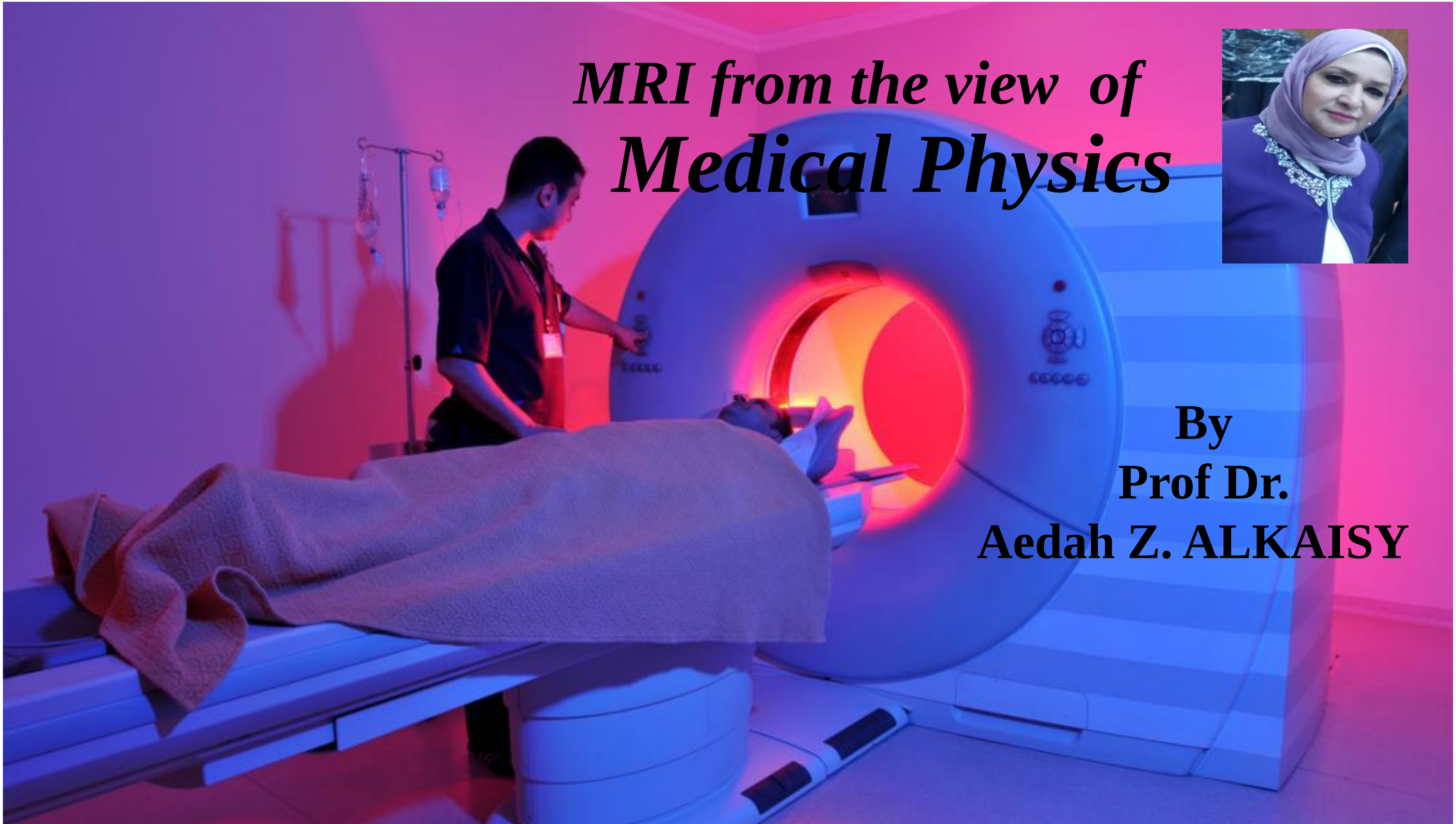

MRI from the view of
Medical Physics

By
Prof Dr.
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بسم الله الرحمن الرحيم

السلام عليكم ورحمة الله وبركاته

Magnetic Resonance Imaging (MRI)

- is one of the medical imaging techniques that does not use X-ray or any other type of harmful radiation. This is done by exploiting the magnetic properties that are already naturally present in the human body. In the past two or three decades, the number of MRI machines has increased dramatically. In my opinion, this device is the best and safest way to see inside the human body without cutting it.

For an MRI we need:

1-a strong magnetic field and

2-radio frequency

Personally, I love the magnetic resonance imaging device and its amazing ability to perform imaging with very high accuracy and in a safe manner without using any type of ionizing radiation.

WE Get FROM The EXAM

- disorders and tumors, strokes, cancers, heart diseases, the digestive system, as well as ligaments, tendons, and joints. We can obtain accurate and detailed 2D or 3D images. MRI is characterized by high-resolution imaging of soft tissues. It is a safe device suitable for adults and children.

HISTORY

- The magnetic resonance device was invented as a result of the accumulation of knowledge in understanding physical, chemical and engineering properties starting approximately in 1950. But its clear and strong entry as a device used in human imaging starting in 1977 was an amazing event in the world of modern medicine and subsequently constituted a revolution in medical imaging techniques.

Magnetism in the human body

- properties already present in the human body. **But** what and where are magnetic properties located inside the human body?! The answer is positively charged protons. These properties can be further enhanced and strengthened within the MRI machine. Protons are found in the nuclei of atoms of elements found in the human body, such as hydrogen, carbon, and oxygen atoms. …etc.

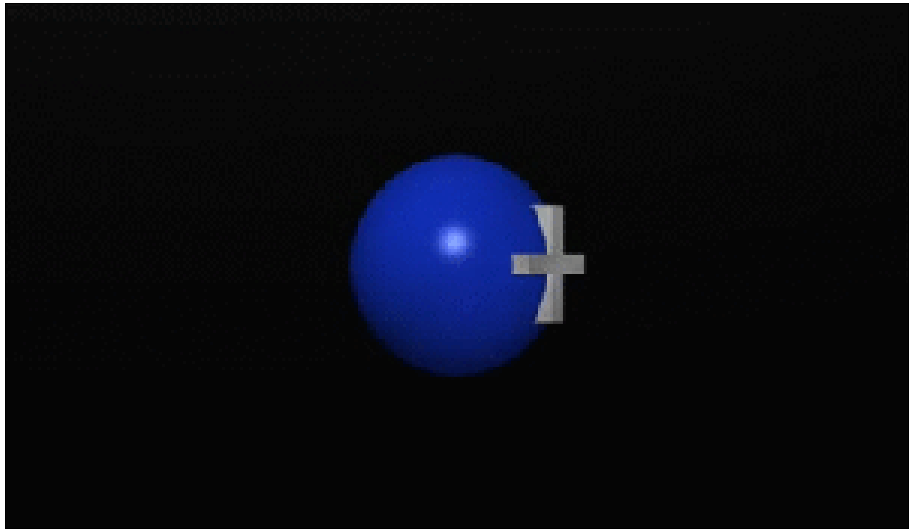
The magnetic resonance signal

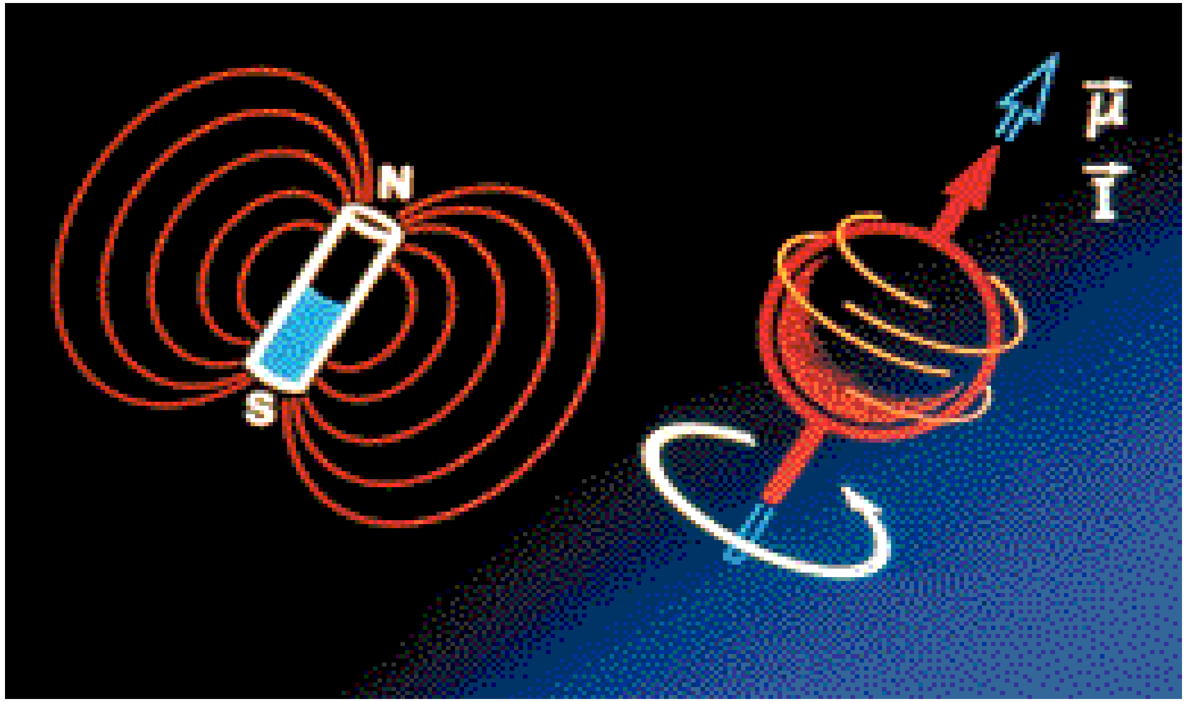
- is taken from the protons present in hydrogen.
- Note that the hydrogen atom consists of only one proton.
- Since the human body is made up of 70% of water, we select the protons of the hydrogen atom in the MRI. The MRI signal used in the medical field depends on the amount of hydrogen. It is present in abundance in most tissues and components of the body.

Protons as magnets in the human body

The question that should come to mind now is how do protons (which are abundant in the human body) have magnetic properties?

- There are two properties that a proton possesses that cause it to behave like a magnet:
- A proton has a positive charge
- The proton moves in a spin motion called a spin
- We know that when there is a moving charge (electricity, for example), a magnetic field is generated. This is what happens to a positively charged proton when it spins. It forms a magnetic field, also called the magnetic moment. Thus, a single proton is like a magnet with a north and south pole.




N
S
μ
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same note to the laws of electromagnetism

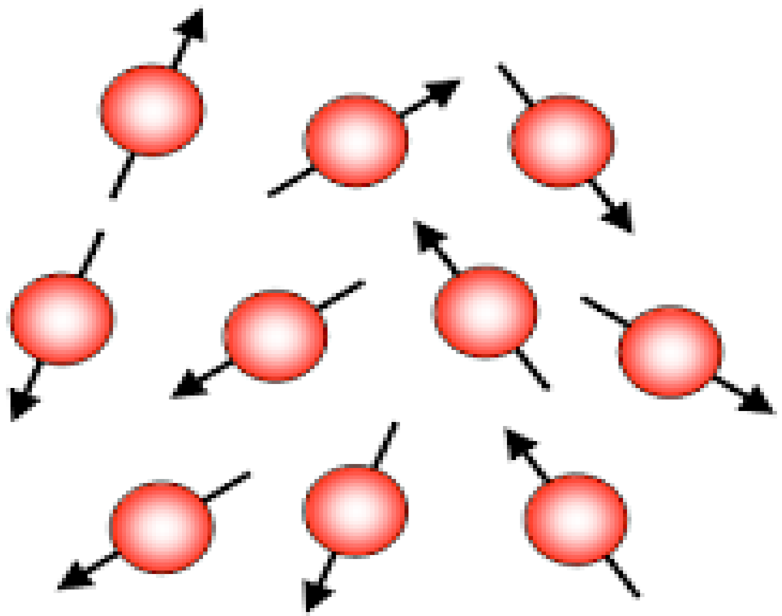
- Electric current can create a magnetic field. Conversely, a changing magnetic field can create an electric current in a physical phenomenon called electro-magnetic induction.
- The spin movement makes the proton look like a magnet with two poles, one north and the other south, in addition to a magnetic field.

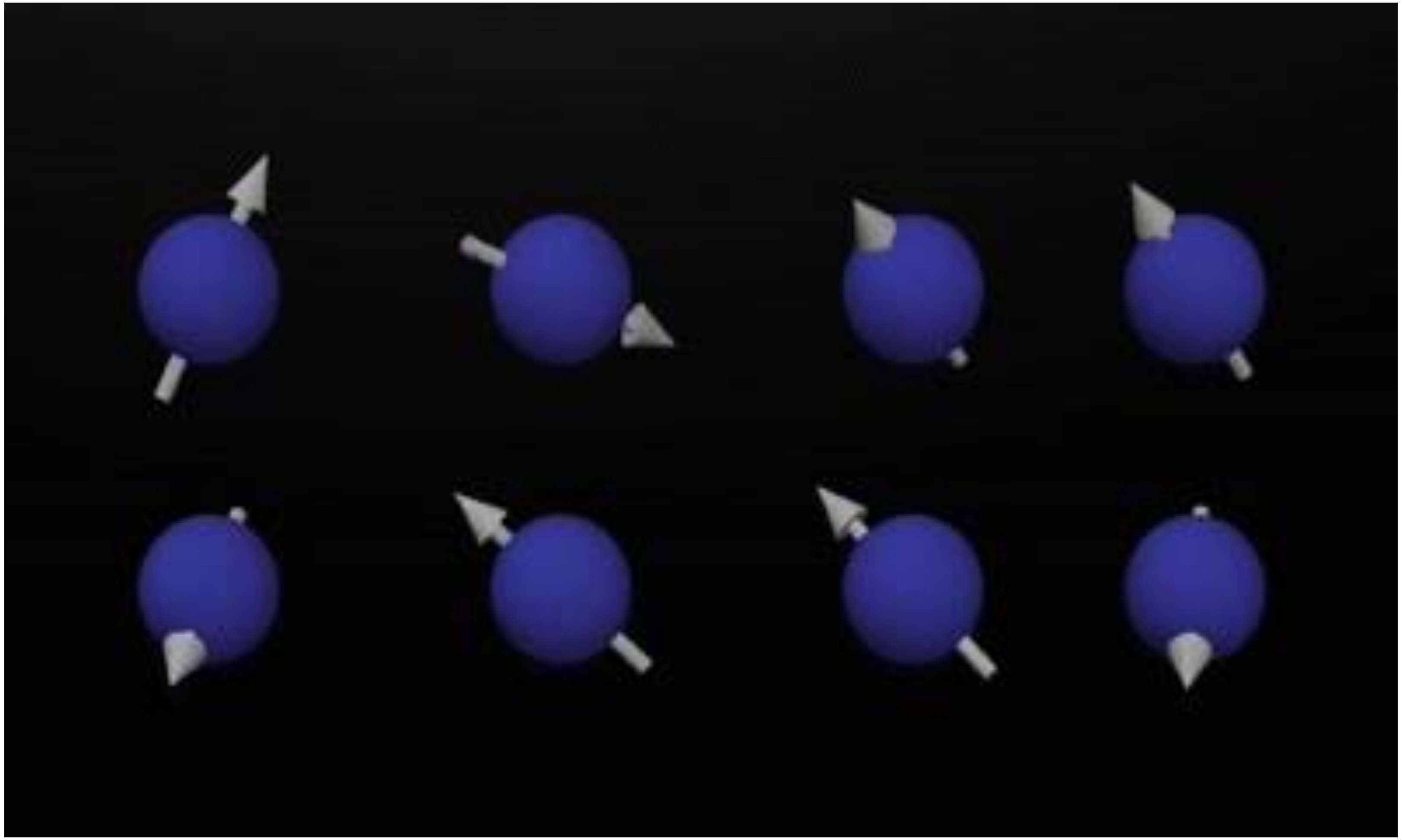
Amazing

Why doesn't a person become a magnet?

- The proton's magnetic field is limited and very small, which does not make humans magnets, despite the existence of the magnetic phenomenon. But the human body contains many hydrogen protons, especially since the human body is 70% water! However, it does not have any significant effect, and the reason is that it scatters the directions in the human body and cancels each other out. We can describe this scientifically by saying that the sum of the total magnetic moments of the protons is zero.

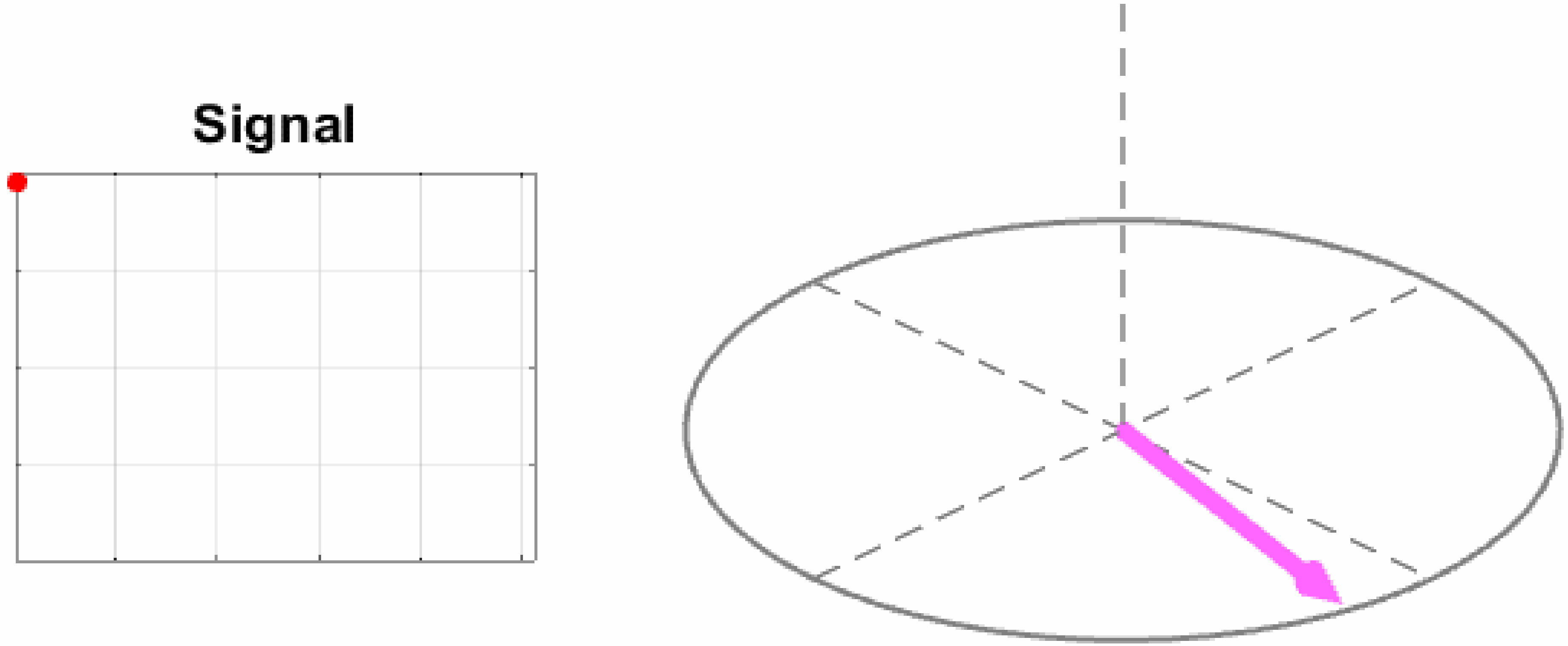
net magnetic moment = zero



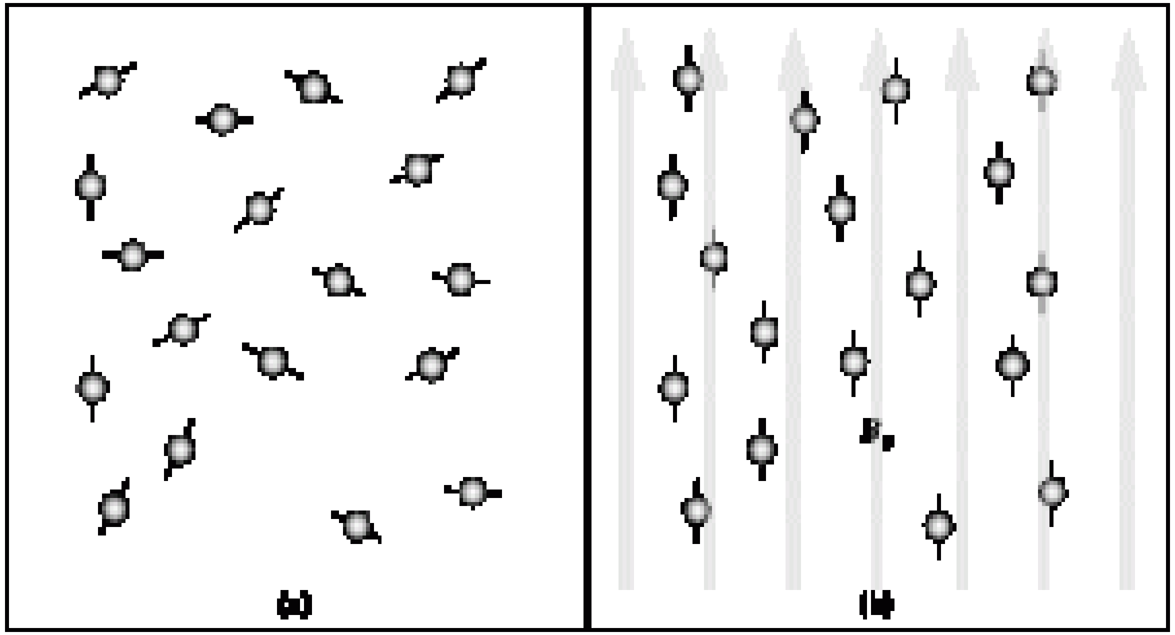


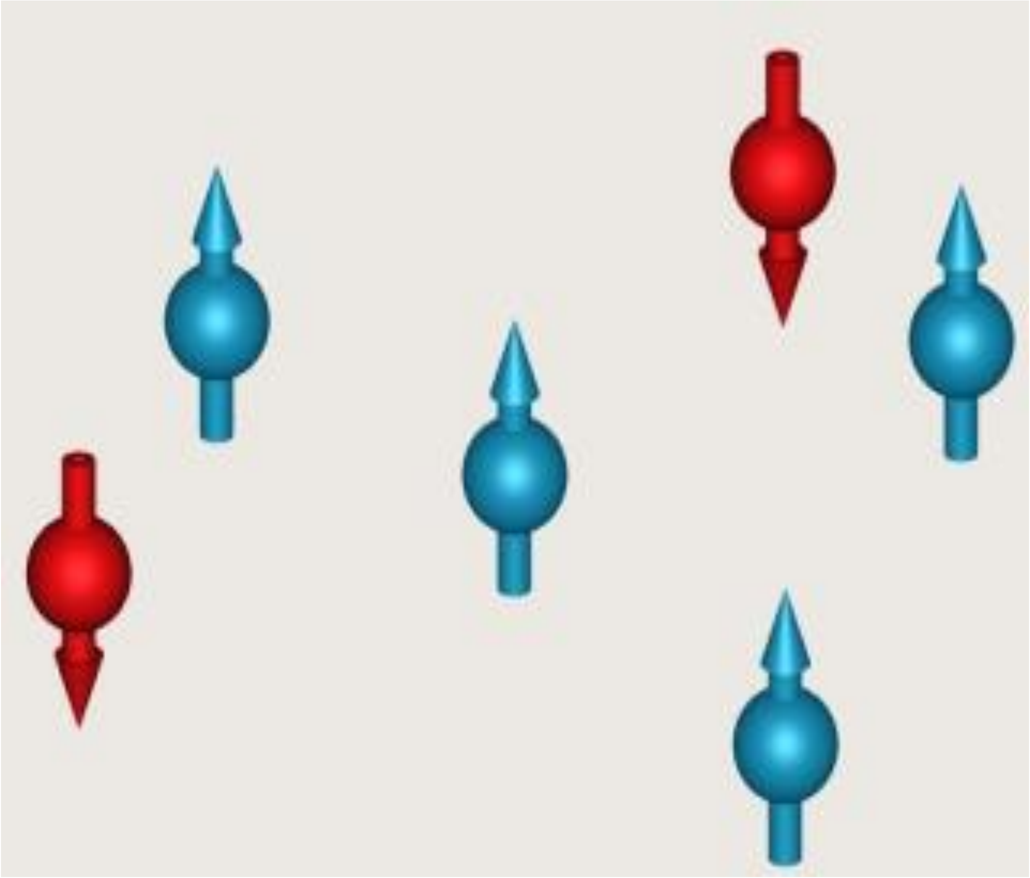
External magnetic field B0 (to utilize protons)

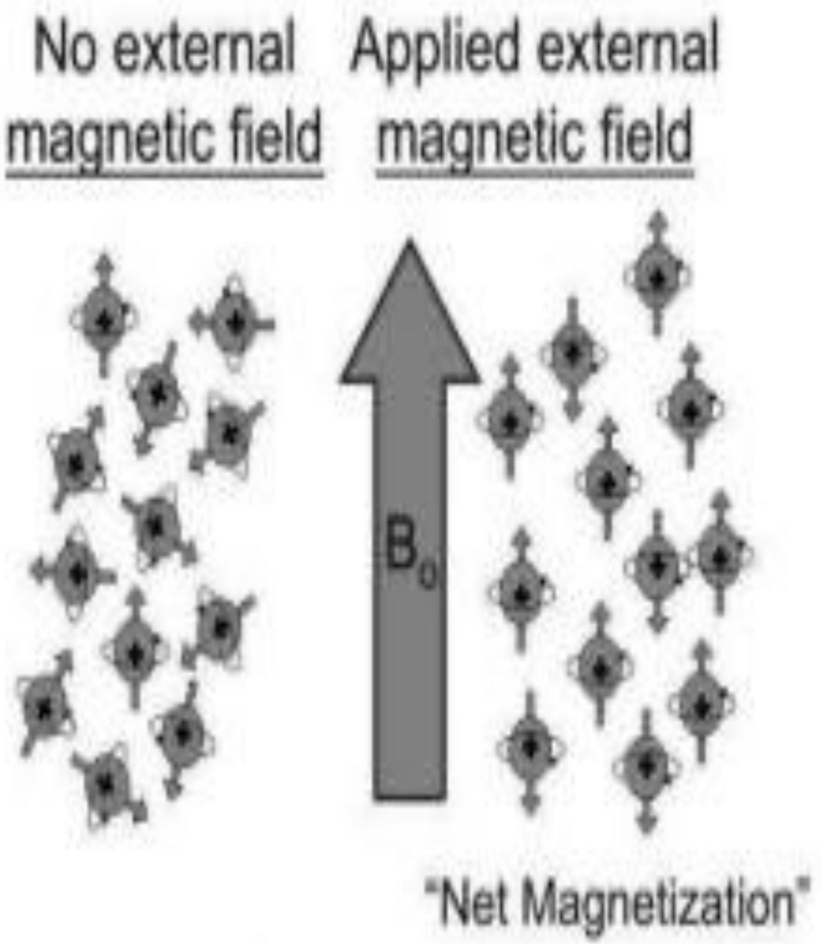
- Now we know that protons in the human body are magnets, but they do not have any general effect and we cannot take any imaging signal from them. But what happens to these scattered protons when they are placed inside an external magnetic field that we call B0?


Signal

- Mainly two things happen:
- The protons will align the directions of their magnetic fields either with or against the direction of the external magnetic field.
- The proton's magnetic field moves in a circular motion called precession

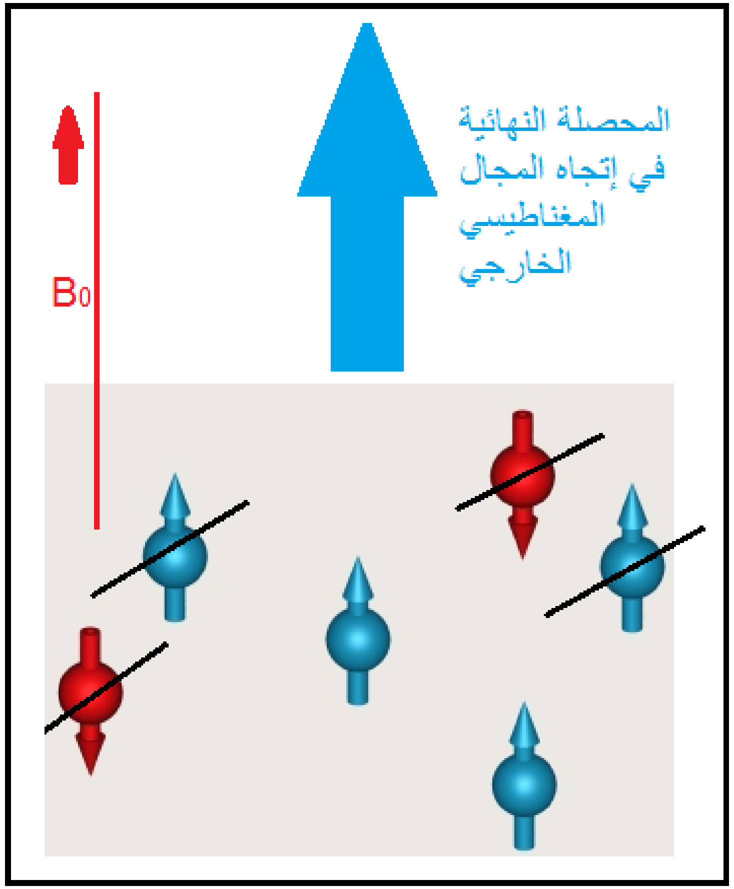






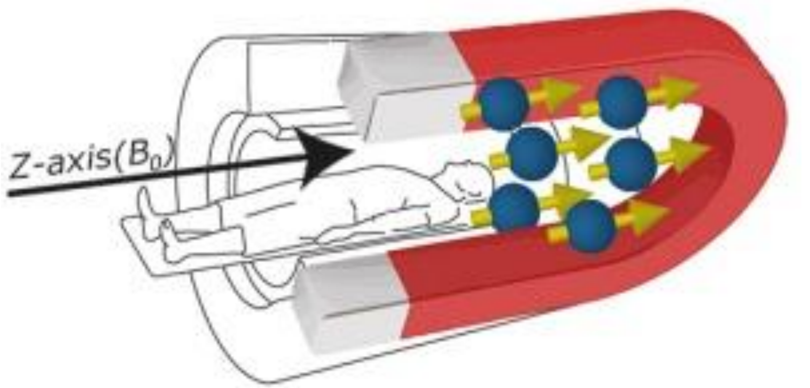
No external magnetic field
Applied external magnetic field
B0
"Net Magnetization"

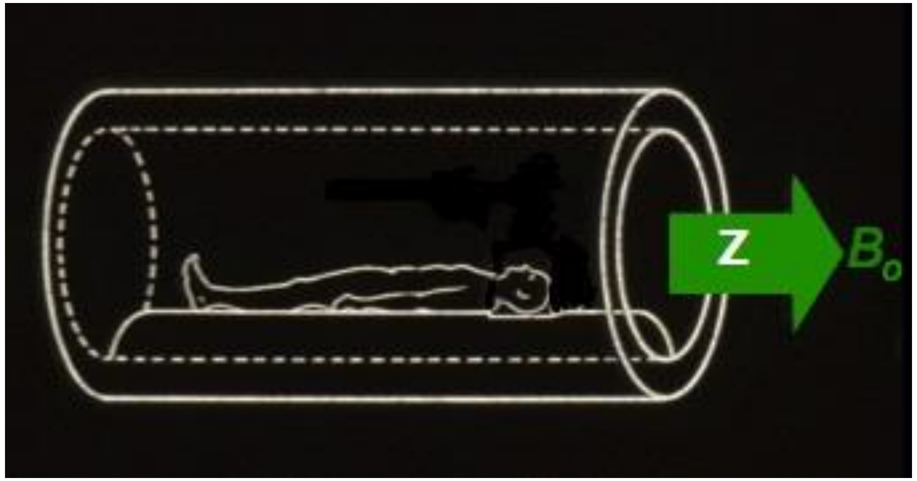
- Opposing magnetic fields cancel each other out, so we will ignore them completely. There remains a small amount of protons (of course their number is in the millions, which is small when compared to the total number) whose magnetic fields are in the direction of the external magnetic field, and thus we have a strong magnetic net magnetic vector that can be exploited in taking the magnetic resonance signal.



External magnetic field = main magnetic field = resonator magnet

- The external magnetic field B0 is the same as the field of the magnet inside the MRI machine and is also called **the main magnetic field**. The directions of magnetic fields in the human body are scattered, but when placed inside an MRI machine, their directions change so that they have a magnetic resultant in the direction of the external magnetic field. All we have to know now is that the external magnetic field **B0** is in the **Z** direction.

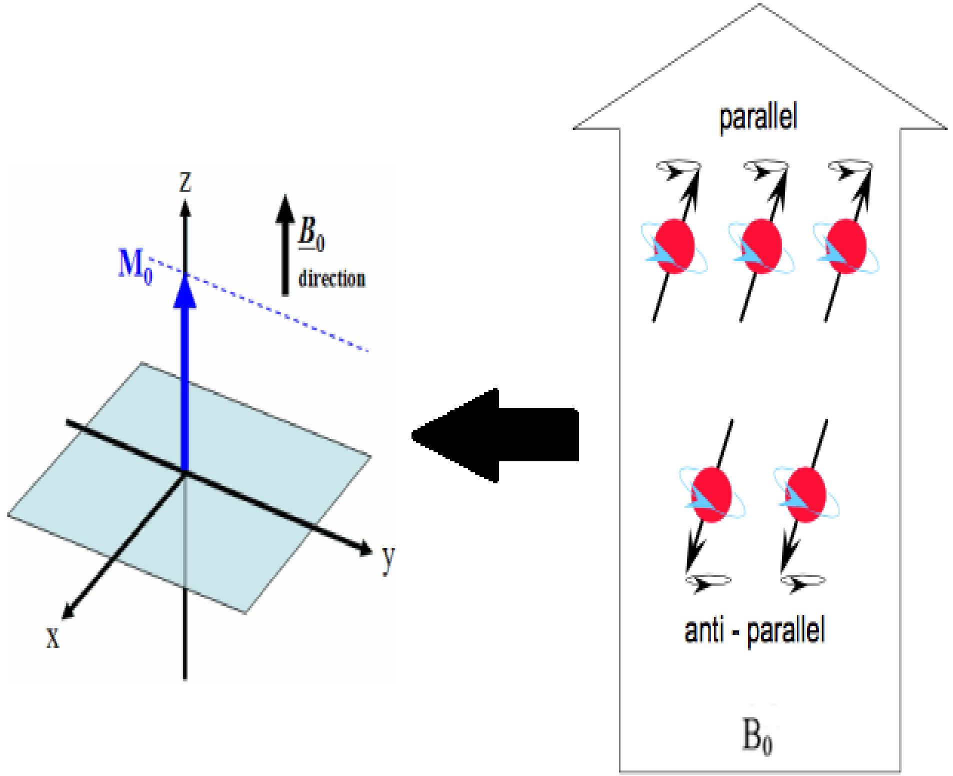




When protons (the human body) are placed inside a strong magnetic field called the external or main magnetic field **B0** (magnetic resonance device), most of them are organized in the same direction as the magnetic field. The remainder is arranged opposite the direction of the magnetic field. Protons facing the magnetic field cancel out an equal number of protons facing the magnetic field. Since the number of the latter is greater, the final result is that the resultant direction of the total magnetic fields of the protons is in the direction of the main magnetic field.

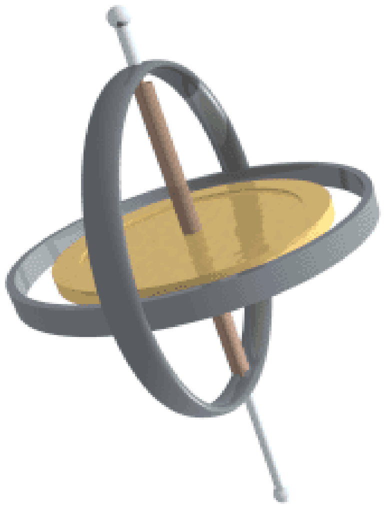
Coordinate system, scientific method and different terminology

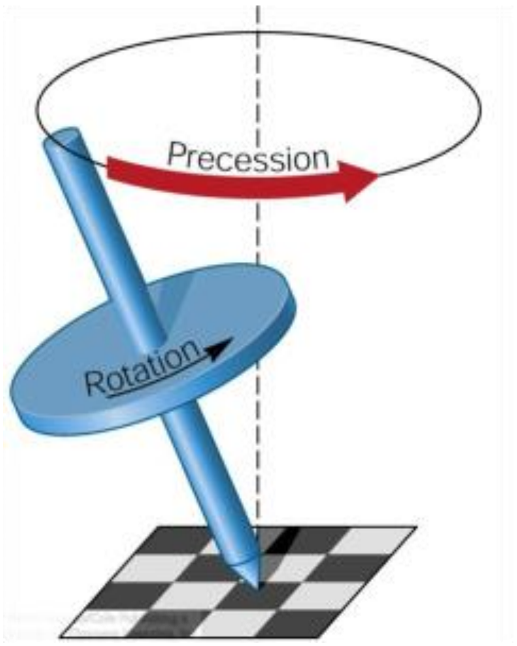
- The coordinate system consists of three directions Z - X - Y. So far we know that the direction Z is the same as the direction of the external magnetic field B0.
- The magnetic resultant (it is in blue in the picture below) we will call it from now on **M0** or **Longitudinal Magnetization** .

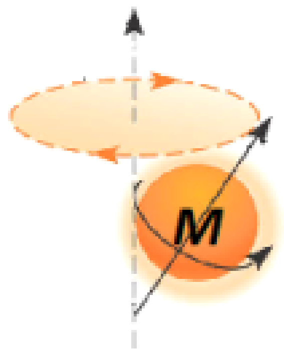


proton movement

- In addition to the spinning movement around the axis, protons move when placed in a magnetic field in a circular movement around the line of the magnetic field, which is called the **Larmor precessional movement .**

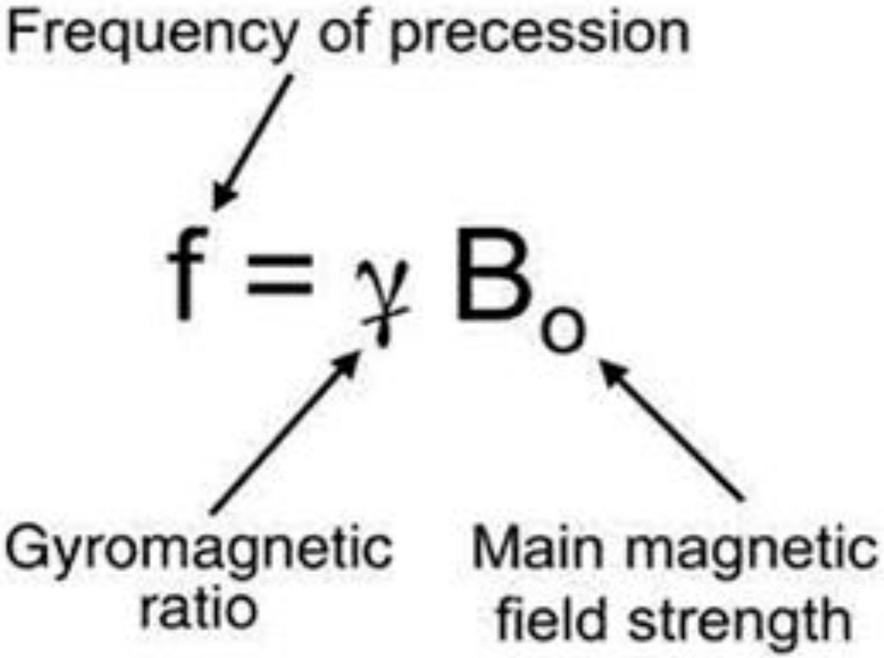




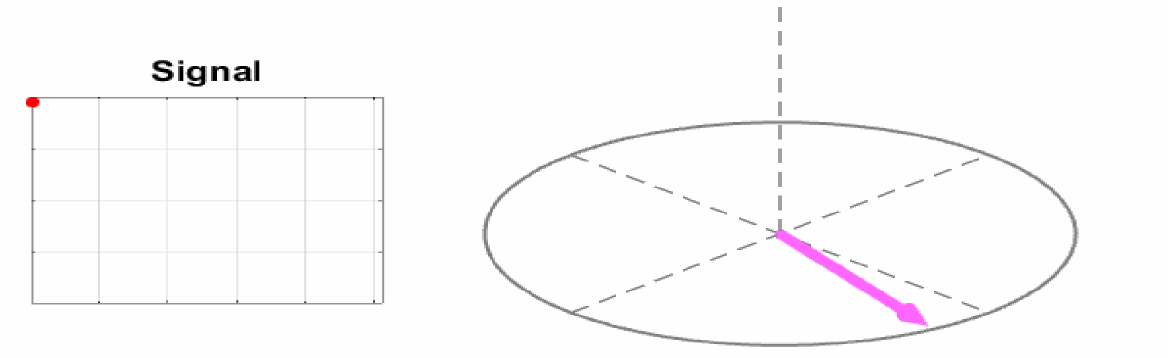


- It remains to say that the speed of Larmor's rotational motion of the proton changes with the strength of the magnetic field. We measure the strength of the magnetic field with the Tesla unit . As for frequency, its unit is the hertz or megahertz (MHz). Rotary motion increases in frequency with increasing magnetic field strength (direct relationship). We call this frequency the Larmor frequency.
- The frequency of this movement at a certain magnetic field can be calculated using **Larmor 's Equation :**

Nucleus or Particle	Gyromagnetic Ratio (γ) in MHz/Tesla
^{1}H	42.58
^{3}He	-32.43
^{13}C	10.71
^{19}F	40.05
^{23}Na	11.26
^{31}P	17.24
electron	-27,204

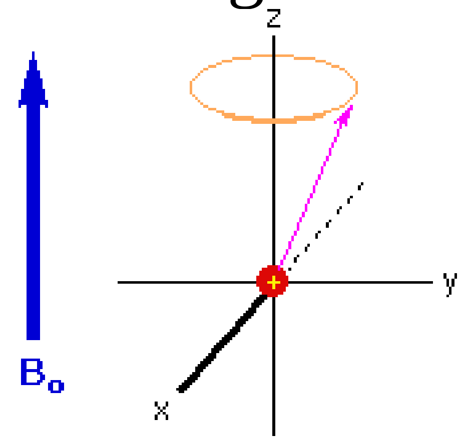


- When protons are placed in the main magnetic field, they acquire a rotational movement called **precession** around the magnetic field lines. This movement has a specific frequency that varies depending on the strength of the magnetic field. The relationship is direct, as the intensity of the magnetic field increases, the frequency of the **Larmor** rotational motion increases.



How is the MRI signal taken?

- Equilibrium State
- Now we know that when protons are placed in a main (external) magnetic field, the sum of their magnetic resultant will be parallel to the main field, and we called it **longitudinal magnetization**. It also rotates around its magnetic field lines with a specific frequency that depends on the strength of the external magnetic field. This is the state of equilibrium



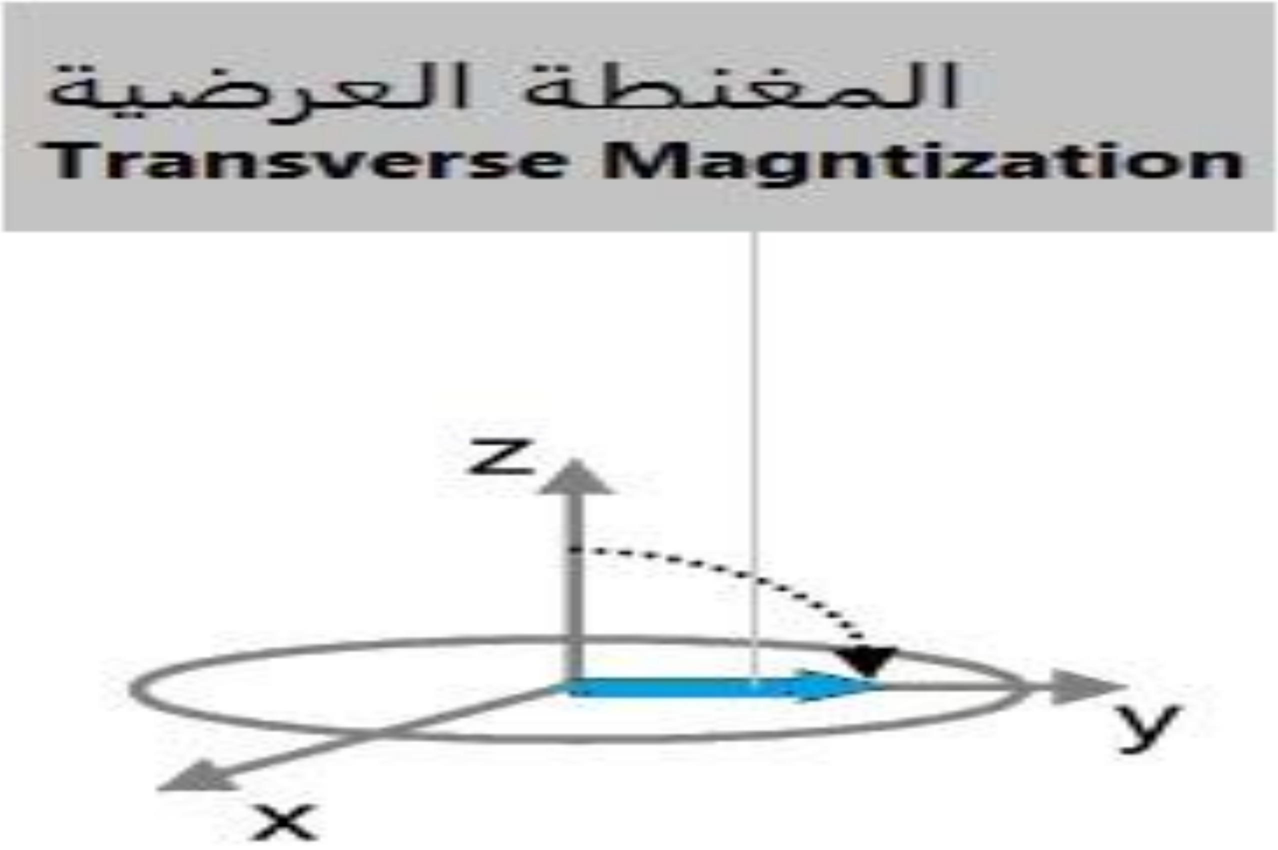
- The equilibrium state cannot take any signal from it because the magnetic signal we want is **immersed** in the direction of the main field. In order to record the signal, it must be excited so that it moves away from the direction of the main field.

When the longitudinal magnetization is in the direction of the external magnetic field, we call this state a state of equilibrium. No signal can be taken from this case and the protons must be excited to be in a direction other than the main magnetic field to obtain a signal.

- **Excitation State**
  Proton excitation can be excited by RF radio waves.

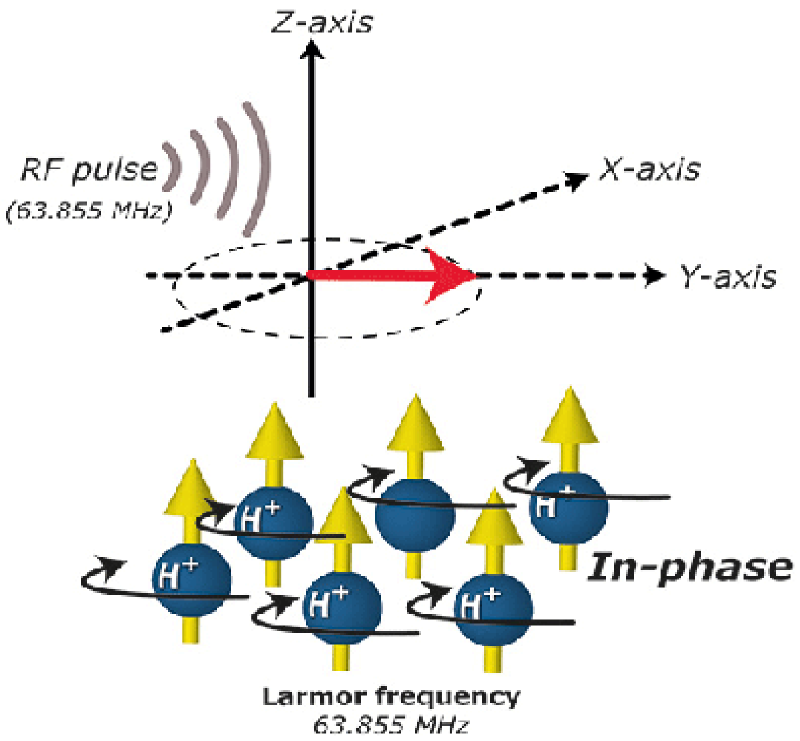
Radio waves are energy given to these protons so that they are able to change the direction of their magnetic resultant from longitudinal magnetization to transverse magnetization .

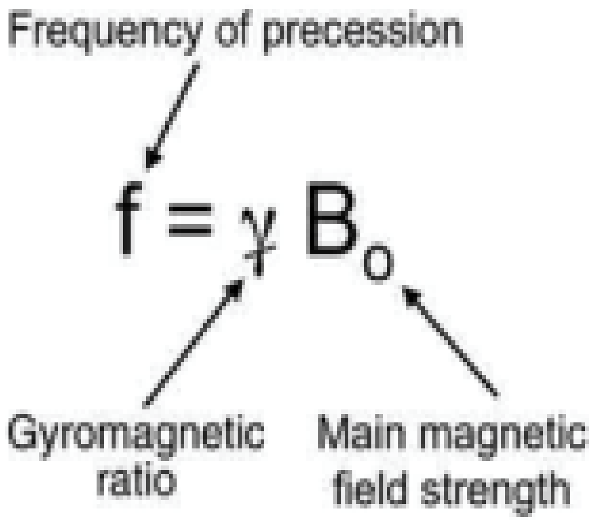
Radio waves are transmitted at a **specific frequency** so that they excite only protons that have the same frequency in a phenomenon called **resonance**. Protons that do not have the same frequency as radio waves are not excited. Thus, we can excite the desired protons by knowing their frequency.


المغنطة العرضية
Transverse Magntization
z
y
x

- The desired protons are excited by sending an RF radio wave frequency equal to the precessional frequency of the Larmor rotation of the protons. Protons gain energy and are able to change the direction of their magnetic fields away from the main magnetic field. In the excited state, the longitudinal magnetization **disappears** and the transverse magnetization increases.

- The frequency of protons can be calculated using Larmor's law and then radio waves equal to this frequency can be sent to be excited.

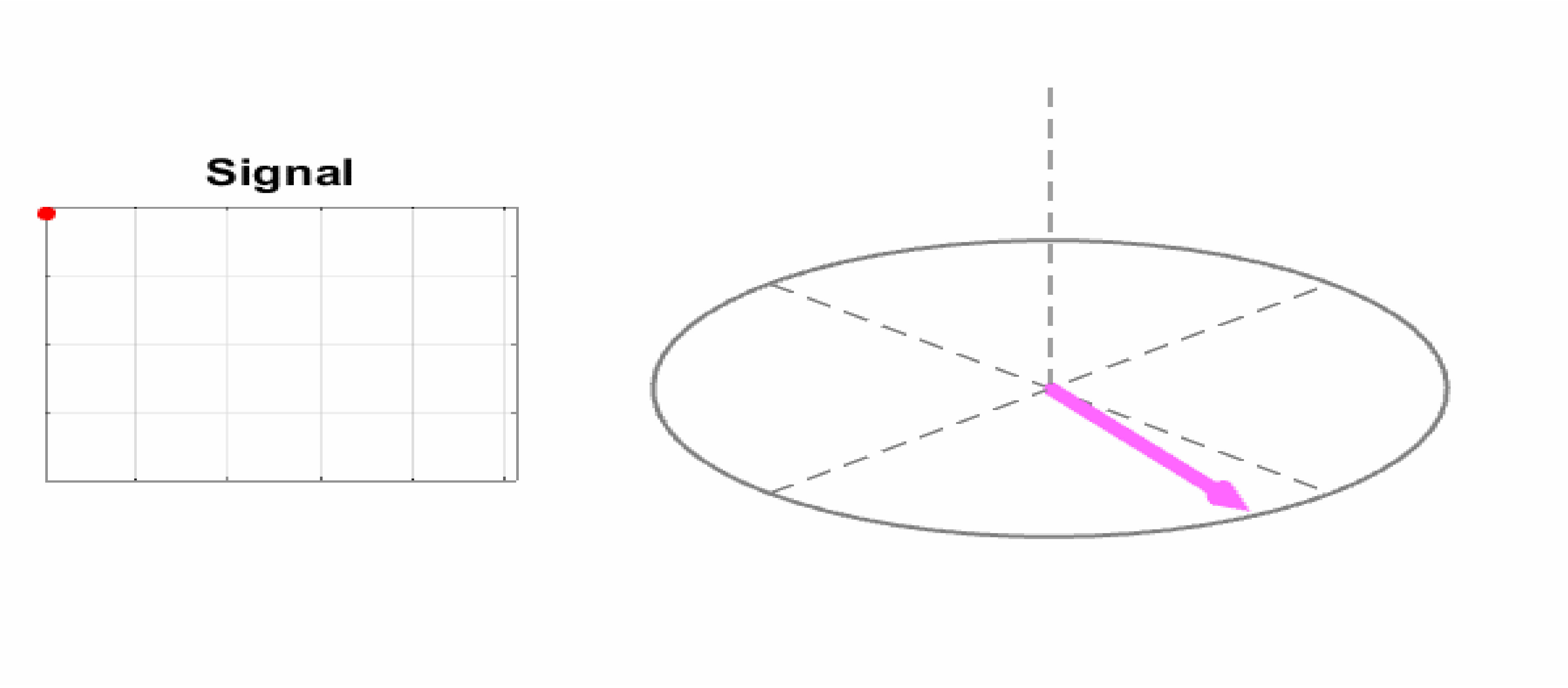




Relaxation

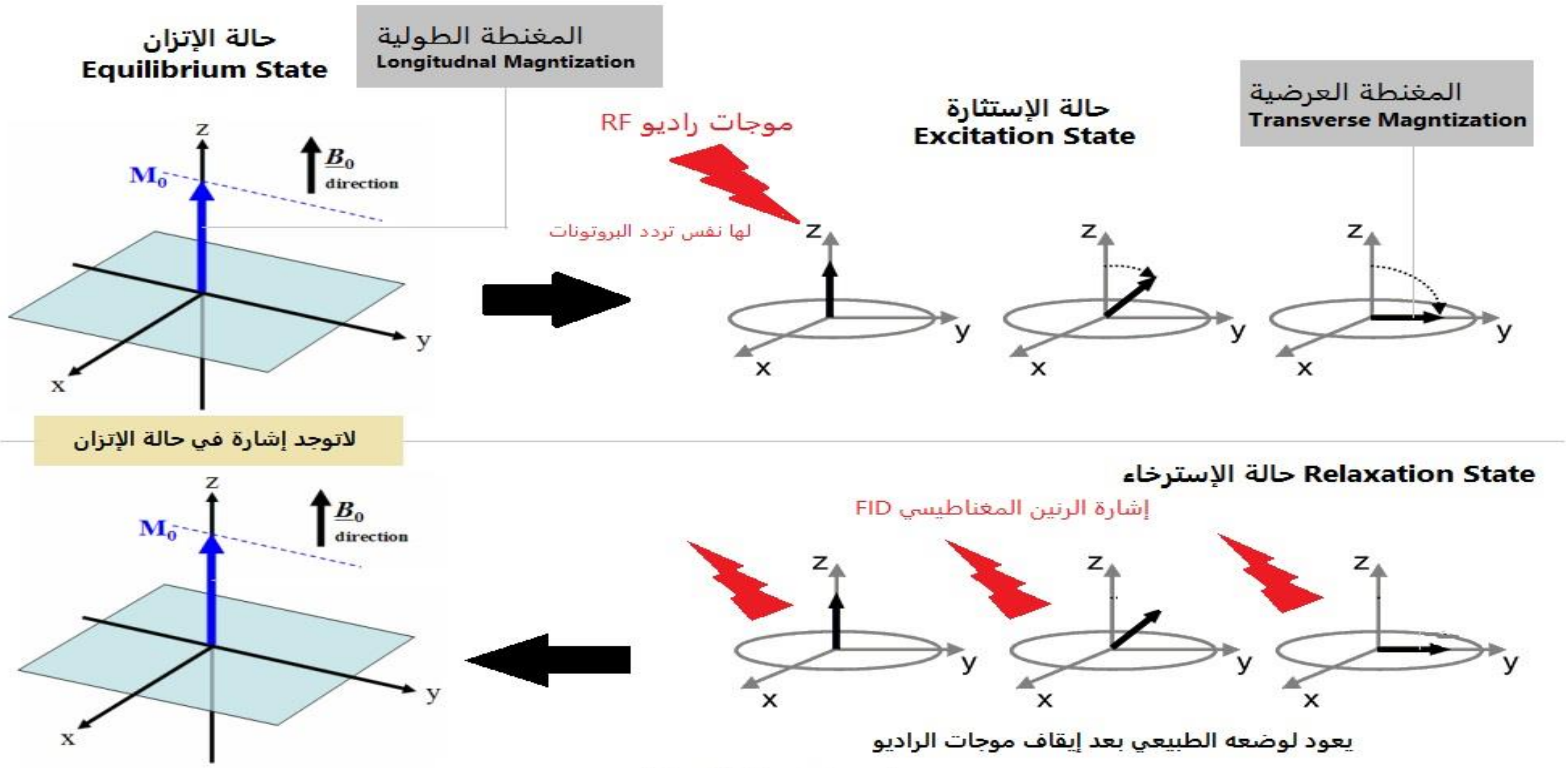
At this stage we obtain an MRI signal . Relaxation occurs after the radio waves stop, as the protons return to equilibrium. Here the transverse magnetization is lost and the longitudinal magnetization is increased. Transverse magnetization is lost because the protons lose the energy they gained from the radio waves and return to their normal state. This loss of energy is the MRI signal and is called **Free Induction Decay**.

MRI signal. We note that the signal is strong during transverse magnetization and gradually decreases until it ends with the completion of longitudinal magnetization



- Resonance is the exchange of energy between RF waves and protons when they have the same frequency. If the frequency differs, energy is not exchanged. I previously said that to excite the protons inside the patient's body, we send them RF radio waves. Excitation only occurs for protons that have a frequency equal to that of radio waves. This gives us an advantage in choosing which protons we want to excite.

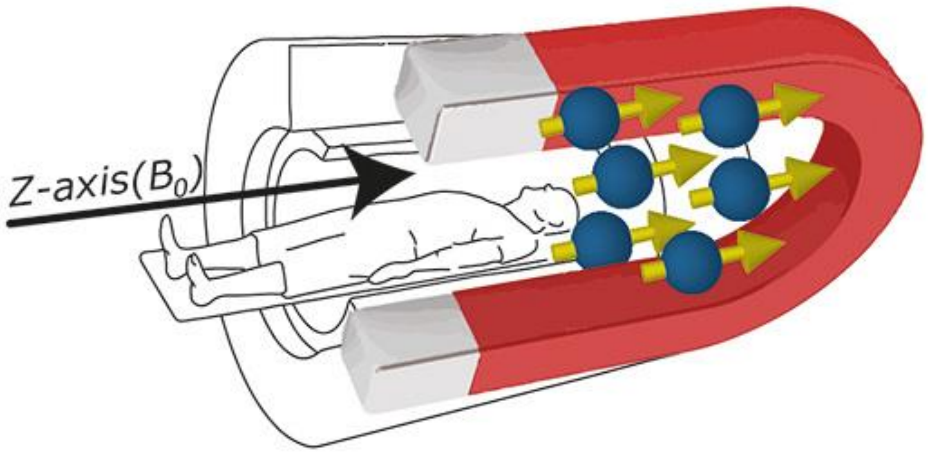
- Radio waves are energy sent towards protons. Protons that have the same frequency as these waves will gain energy and be able to direct their energy in a direction opposite to the main magnetic field. The magnetic resultant of the protons will move from longitudinal magnetization to transverse magnetization.
- After stopping the radio waves, the protons will lose the energy they gained and return to their normal state from the excited state to the equilibrium state. The MRI signal is this energy that the protons lost as they returned to their normal state.



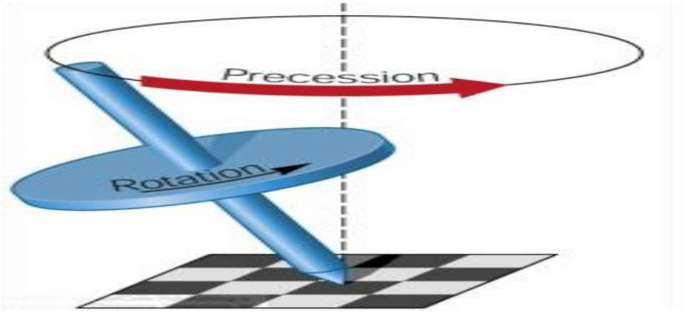
حالة الإتزان
Equilibrium State
المغنطة الطولية
Longitudnal Magntization
z
B_0
direction
M_0
y
x
موجات راديو RF
لها نفس تردد البروتونات
حالة الإستثارة
Excitation State
المغنطة العرضية
Transverse Magntization
z
y
x
لاتوجد إشارة في حالة الإتزان
حالة الإسترخاء Relaxation State
إشارة الرنين المغناطيسي FID
يعود لوضعه الطبيعي بعد إيقاف موجات الراديو

Applying what we have learned to the MRI machine

To take an MRI we initially need a strong magnet and RF radio waves. The magnetic resonance device is a magnet and we called it the (main) external magnetic field. Its function is to create a magnetic resultant for the scattered protons so that their results are in the direction of the external magnetic field. In this way, we make the patient a magnet.



- The second thing is RF radio waves, and their function is to break the state of equilibrium by exciting the two protons and giving them some energy. After stopping these waves, the protons lose the gained energy and return to their normal state in equilibrium. The amount of energy loss is the MRI signal.
- RF radio waves are transmitted and the signal is received by so-called RF coils . It is placed directly on the patient and has different shapes and types.



Types of MRI devices

Closed MRI machine

- The device is closed around the patient except for two openings. It may cause fear and discomfort in some patients, especially those who suffer from claustrophobia. This device is common and produces a strong external magnetic field, which makes it suitable for most hospitals, and it gives better images than all other types.

Open MRI machine

- This device may be suitable for those who suffer from fear of confined spaces and children, but it produces a lower magnetic field than the first type, and the examination may take longer. Also, the image quality is lower than the first type, but it is very acceptable and can be diagnosed using it. This device is purchased by hospitals as needed. Some large centers may have this device in addition to the main closed device. This device is also suitable for interventional radiology.

Magnetic resonance imaging device for the limbs

Thanks