# Module 2:
# Basic MR Physics

# Magnetic Resonance Imaging


An MR scanner consists of an electromagnet with a very strong magnetic field (1.5 - 7.0 Tesla)

Earth's magnetic field = 0.00005 Tesla

3 Tesla is 60,000 times stronger than the Earth's magnetic field.

# What MRI Measures

- MRI is an extremely versatile imaging modality that can be used to study both brain structure and brain function.

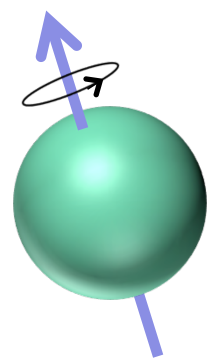
- Both structural and functional MRI images are acquired using the same scanner.

- Different types of brain images can be generated to emphasize contrast related to different tissue characteristics.

# Principles of MRI

- All magnetic resonance imaging techniques rely on a core set of physical principles.
- To understand we must begin by studying a single atomic nuclei and illustrate its impact on the generated MR signal.
- In particular we focus on hydrogen atoms consisting of a single proton.

Protons can be viewed as positively charged spheres which are always spinning. They give rise to a net magnetic moment along the axis of the spins.



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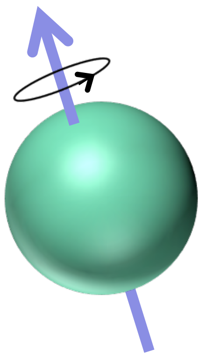
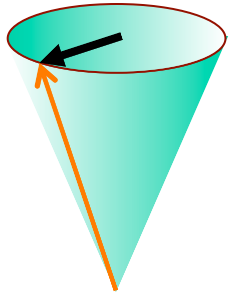
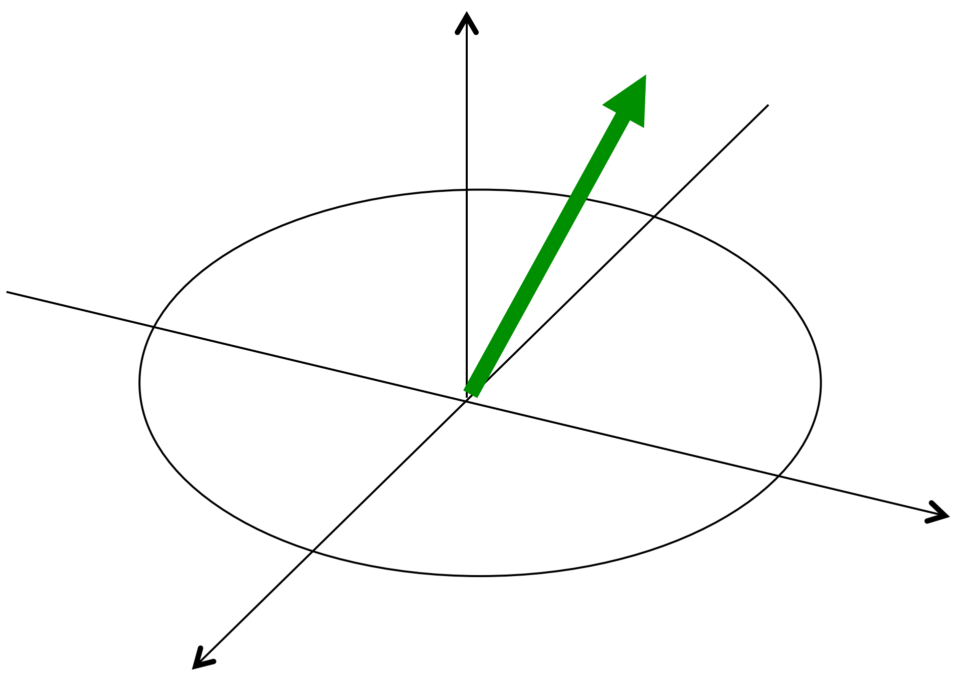


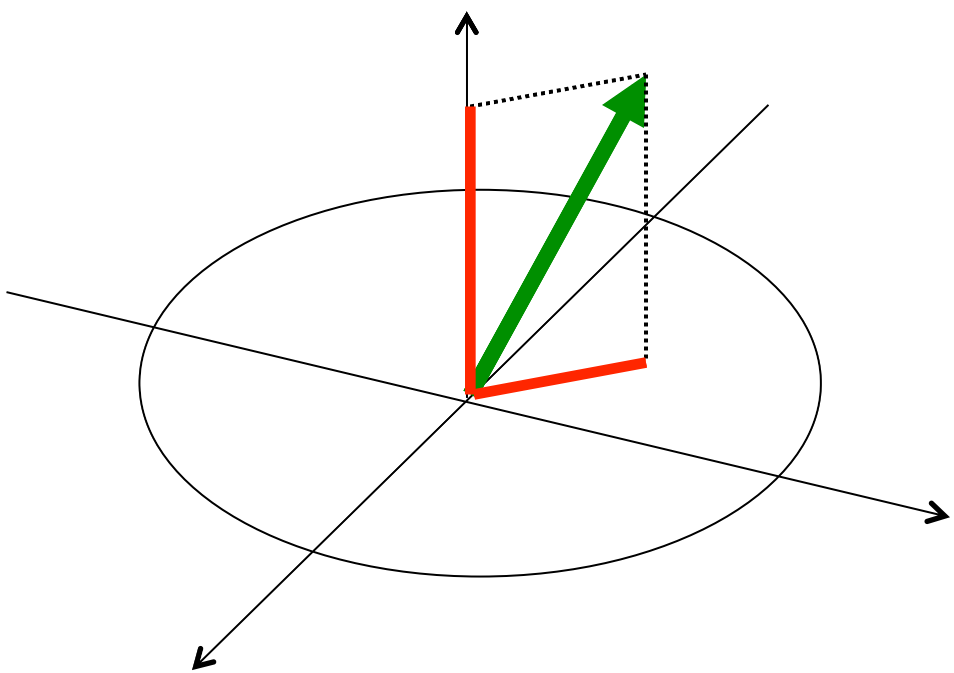


# Net Magnetization

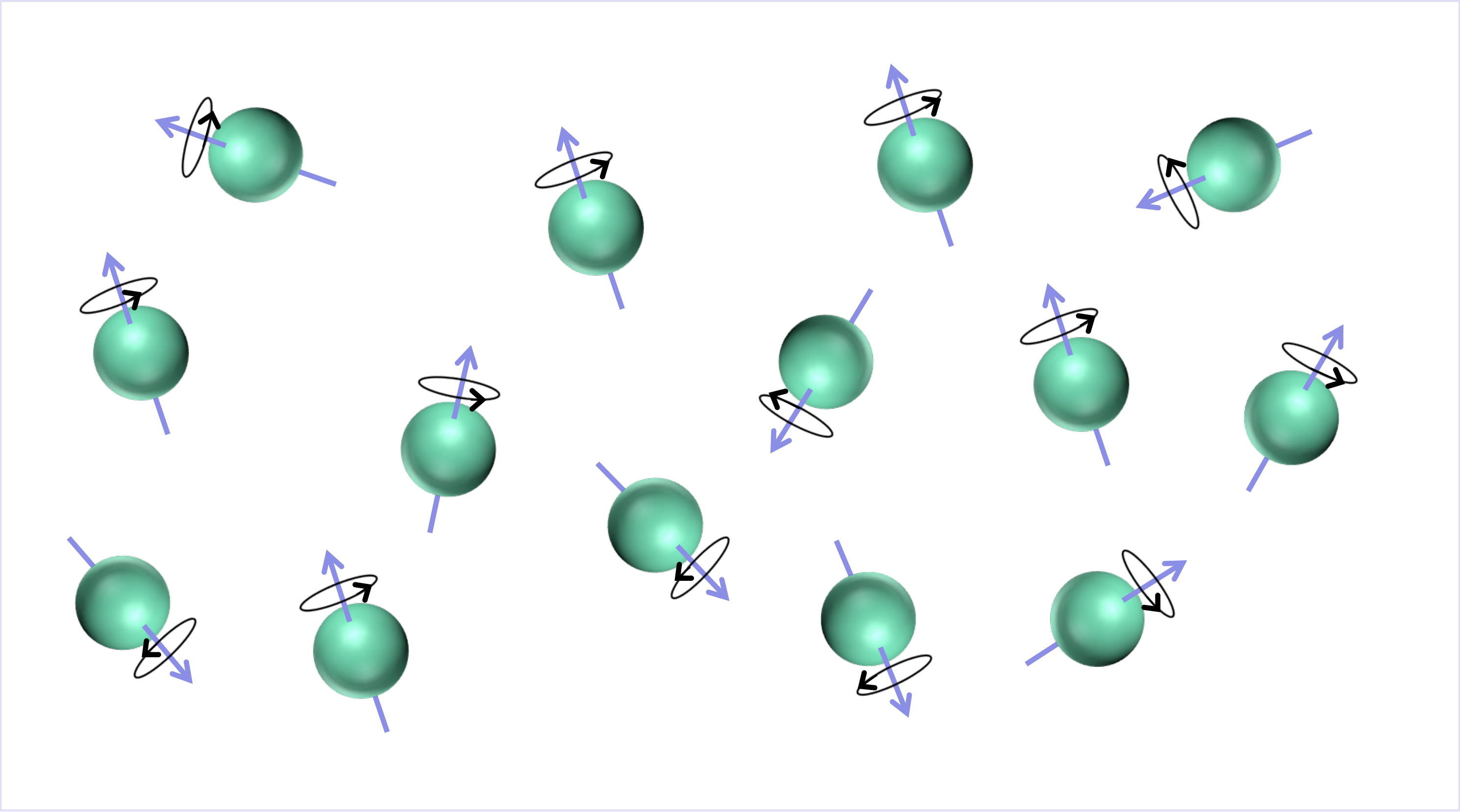
- We cannot measure the magnetization of a single proton using MR, instead we measure the net magnetization of all nuclei within a volume.

- The net magnetization M can be viewed as a vector with two components.
  - A longitudinal component parallel to the magnetic field.
  - A transverse component perpendicular to the field.

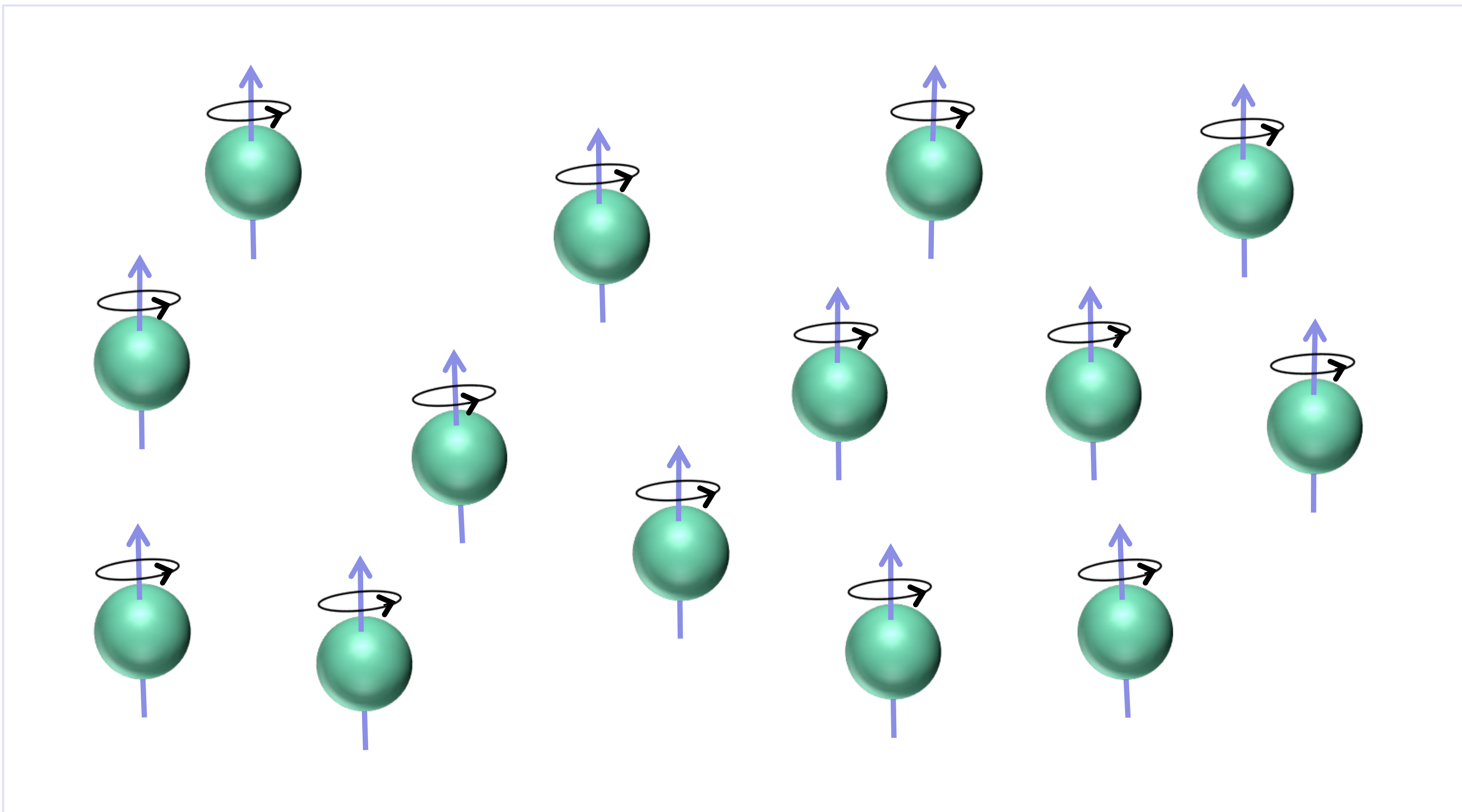


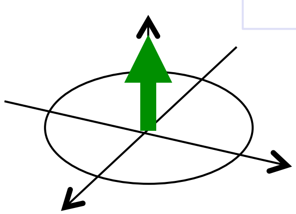


In the absence of an external magnetic field, the nuclear magnetic moments are randomly oriented. There is no net magnetization.

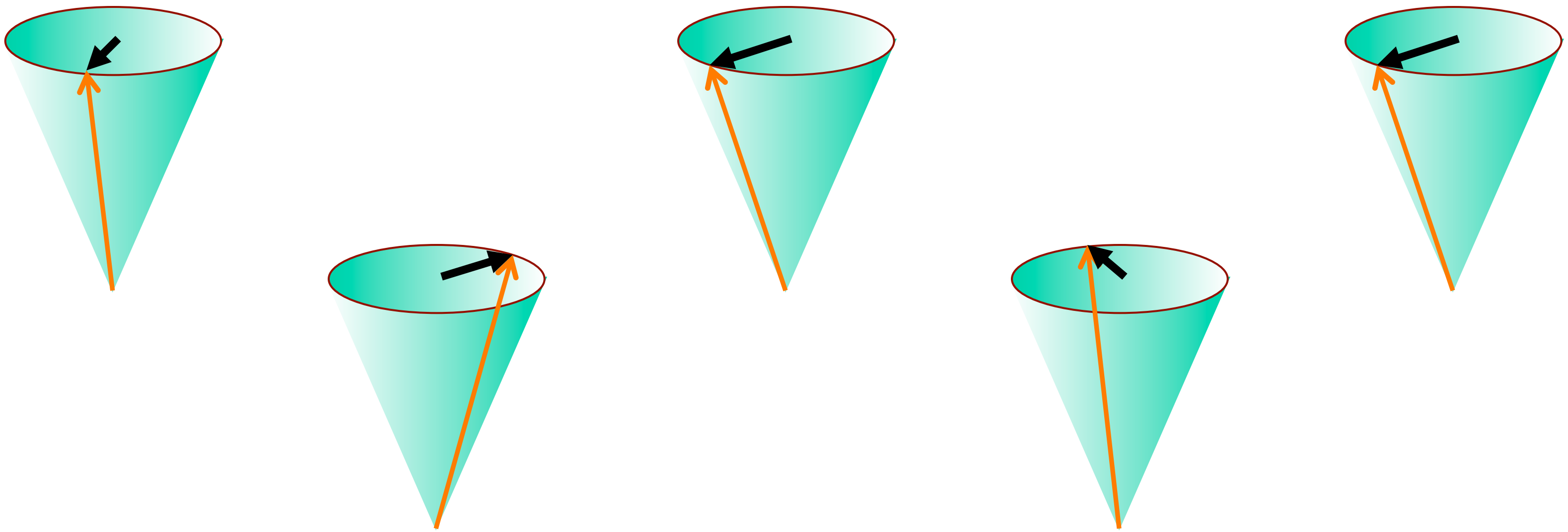


When placed in a strong magnetic field, the nuclei align with the field. This creates a net longitudinal magnetization in the direction of the field.

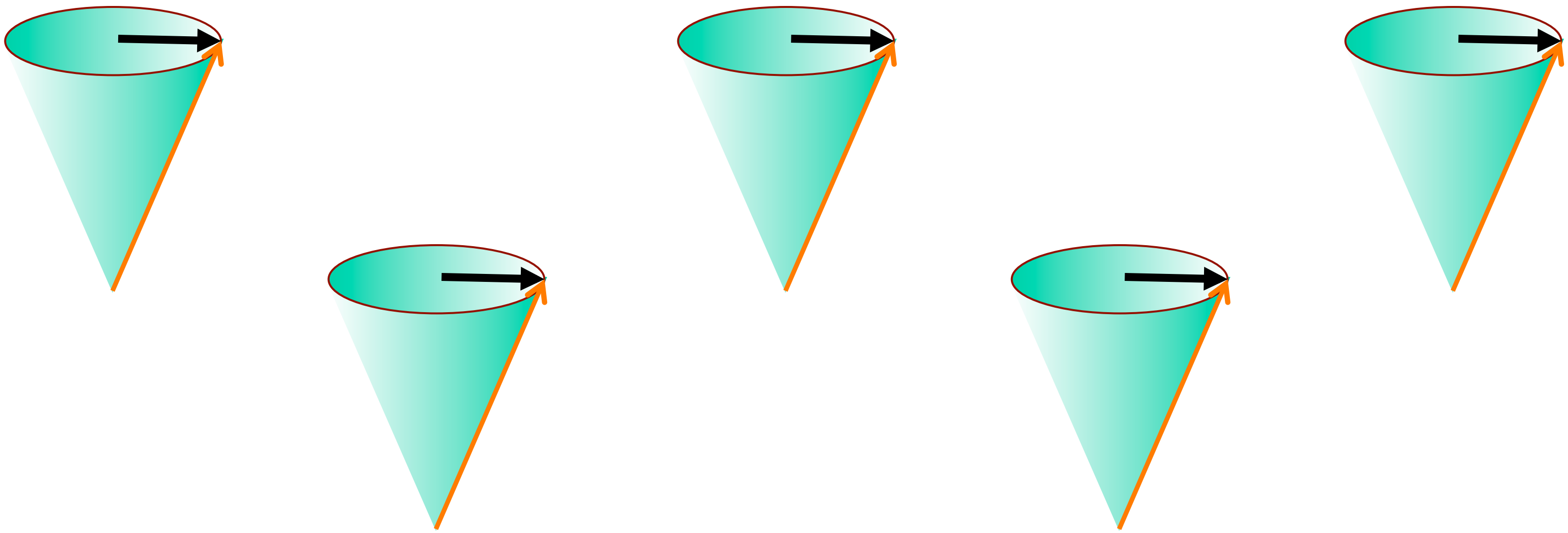




The nuclei precess about the field with an angular frequency determined by the Larmor frequency but at a random phase.



A radio frequency (RF) pulse is used to align the phase and ‘tip over’ the nuclei. This causes the longitudinal magnetization to decrease, and establishes a new transversal magnetization.



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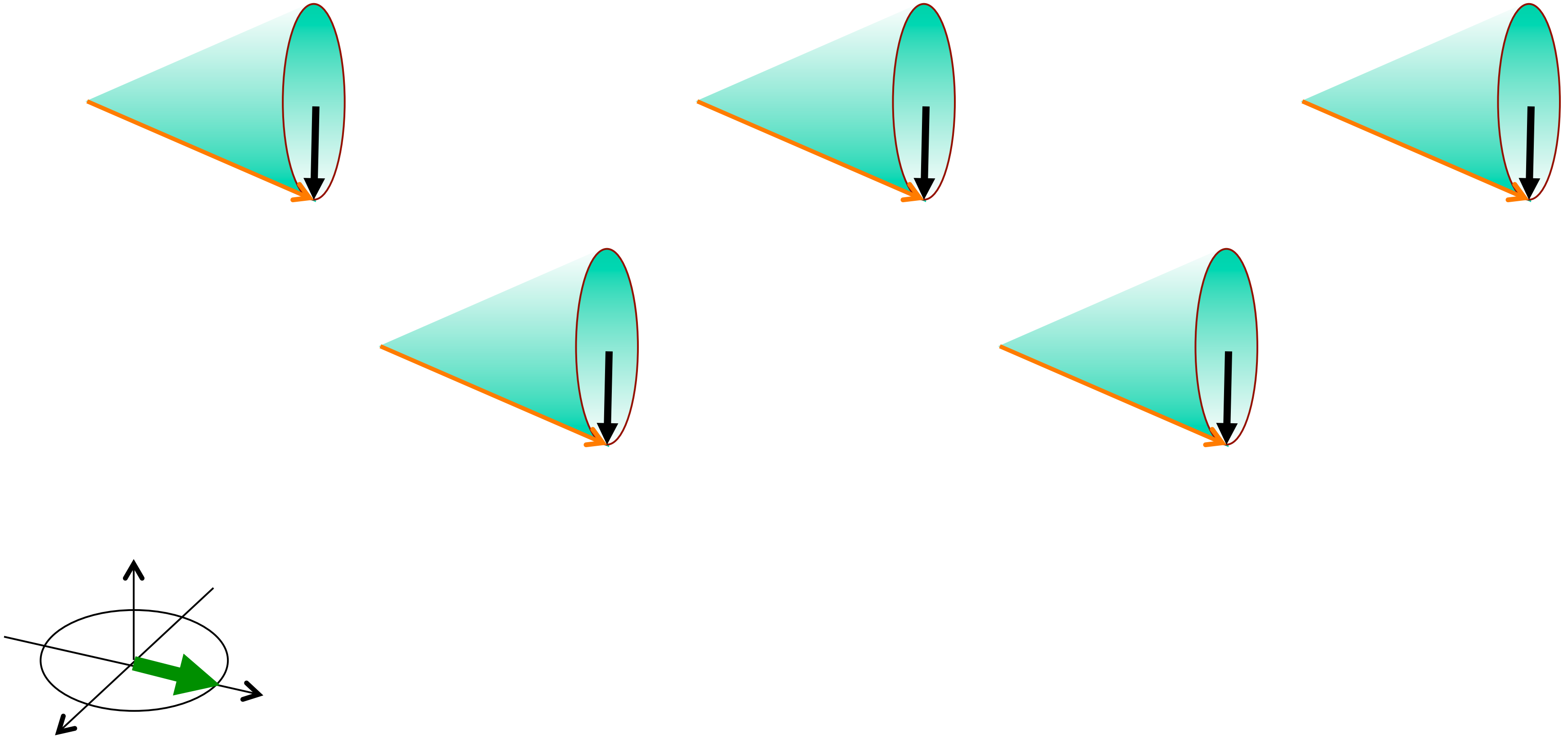


# Relaxation

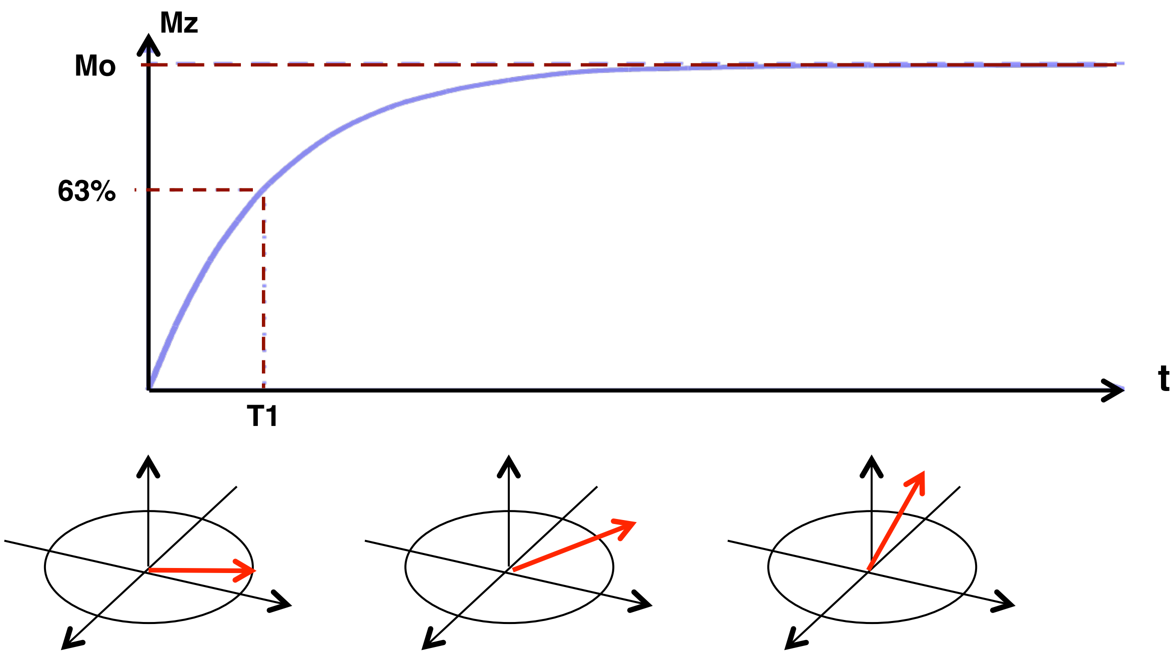
- After the RF pulse is removed, the system seeks to return to equilibrium.
- The transverse magnetization starts to disappear (transversal relaxation), and the longitudinal magnetization grows back to its original size (longitudinal relaxation).
- During this process a signal is created that can be measured using a receiver coil.

# Relaxation

- Longitudinal Relaxation is the restoration of net magnetization along the longitudinal direction as spins return to their parallel state.
  - Exponential growth described by time constant T1

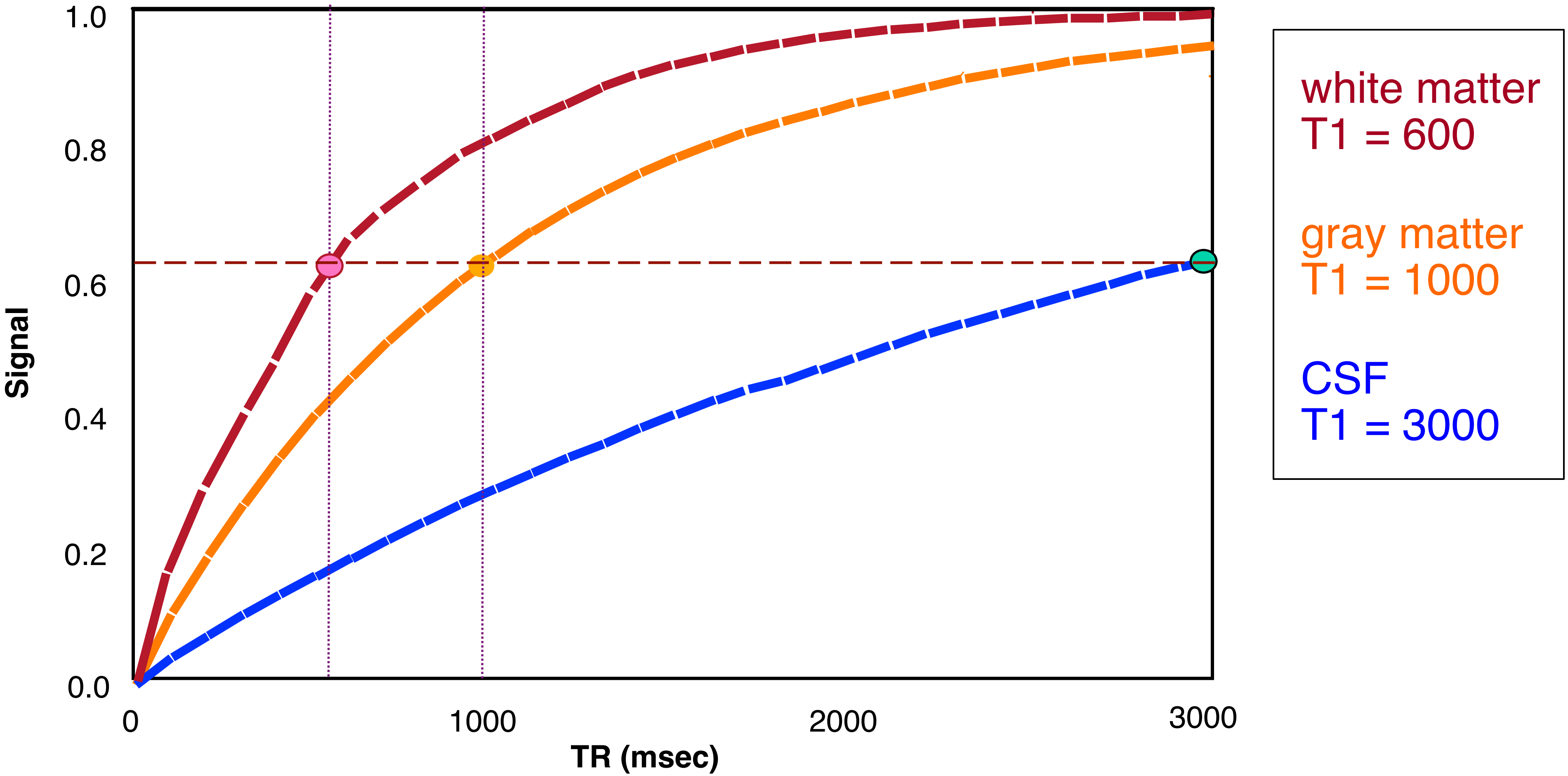
- Transverse Relaxation is the loss of net magnetization in the transverse plane due to loss of phase coherence.
  - Exponential decay described by time constant T2

# Longitudinal Relaxation Time

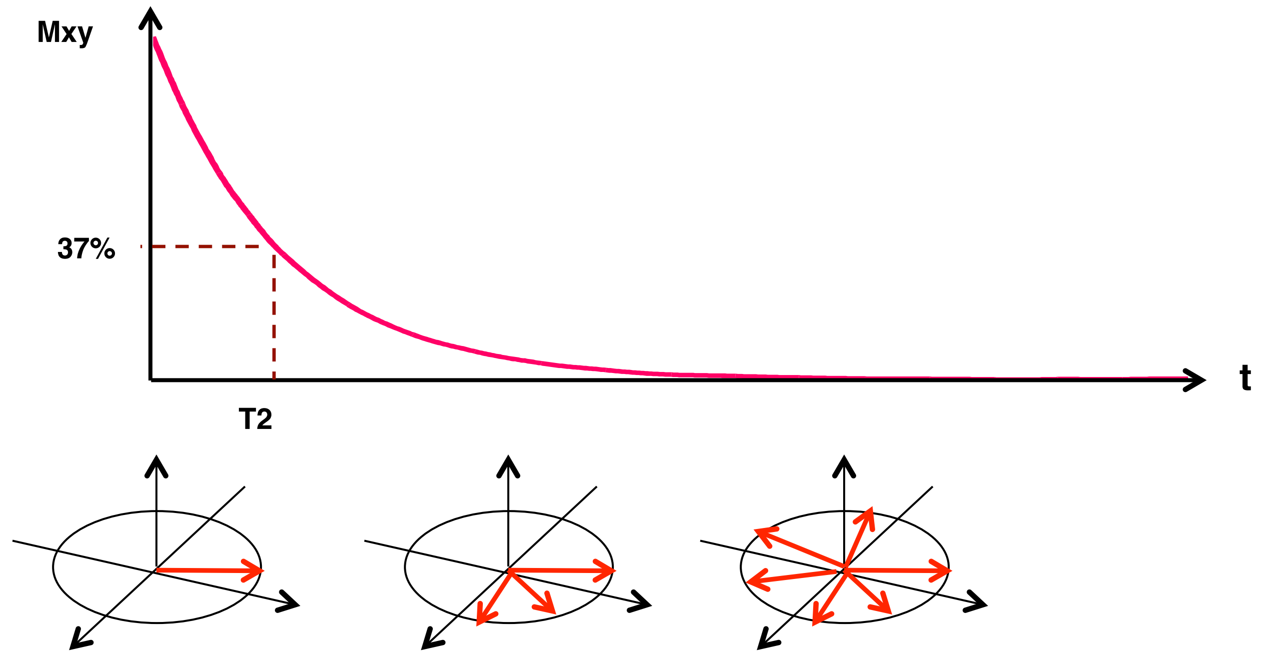



The restoration of longitudinal magnetization is described by a time constant T1.

# Longitudinal Relaxation Time



# Transverse Relaxation Time




The decay of magnetization due to interaction between nuclei is described by a time constant T2.

# Image Contrast

- By altering how often we excite the nuclei (TR) and how soon after excitation we begin data collection (TE) we can control which characteristic is emphasized.

- The measured signal is approximately

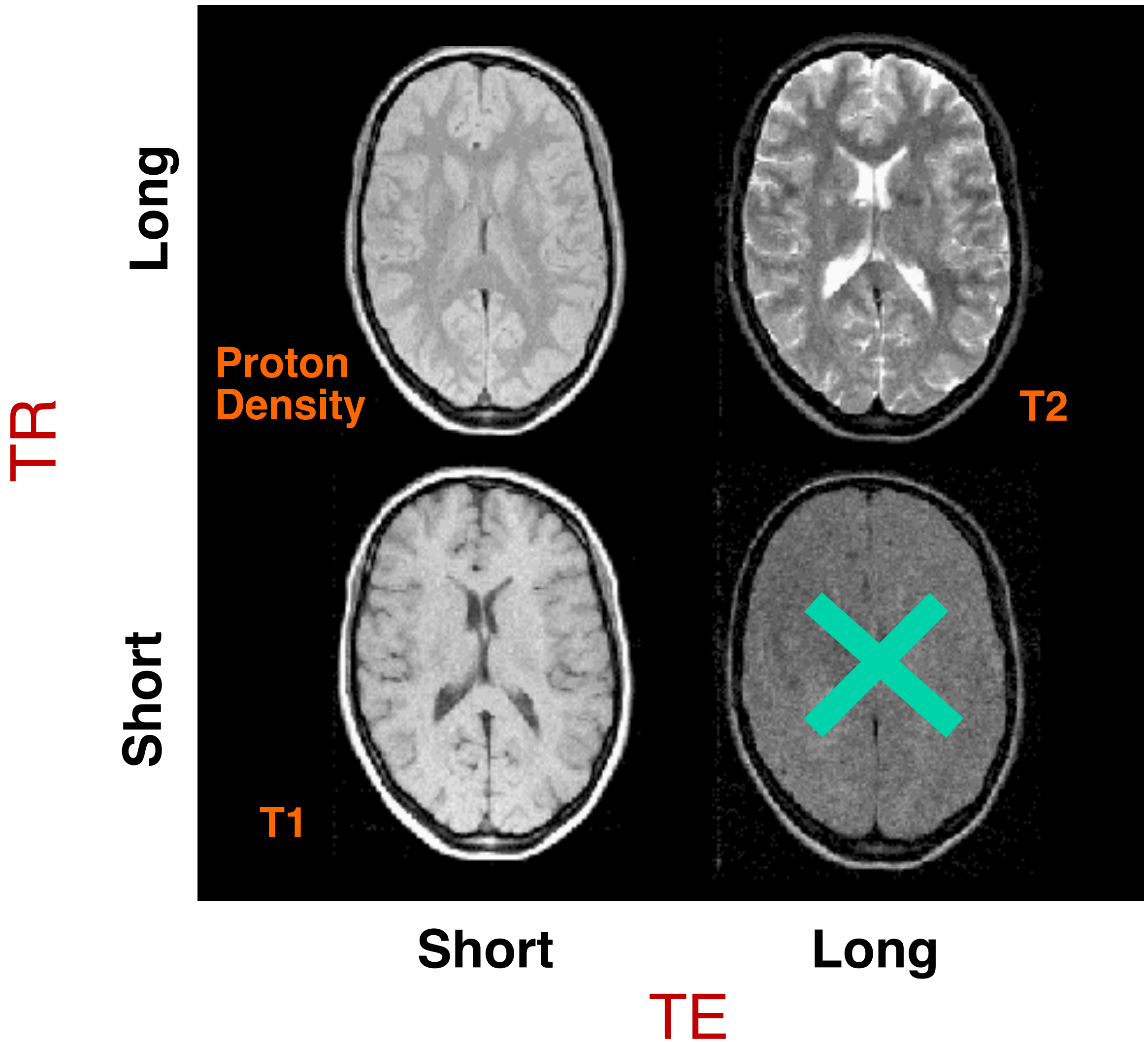
$$M_0(1-e^{-TR/T_1})e^{-TE/T_2}$$

where $T_1$ and $T_2$ are tissue properties.

# Image Formation

- The goal of MRI is to construct an image, or a matrix of numbers that correspond to spatial locations.
- The image depicts the spatial distribution of some property of the nuclei within the sample.
- This could be the density of nuclei or the relaxation time of the tissues in which they reside.

# Image Contrast




$$M_0(1-e^{-TR/T_1})e^{-TE/T_2}$$

TE (echo time) - the time between excitation and data collection.

# fMRI Contrast

- $T_2$* is the combined effect of $T_2$ and local inhomogeneities in the magnetic field.
- The scanner can be programmed to eliminate the effects of these inhomogeneities, or alternatively emphasize them.
- The latter types of procedures form the basis of BOLD fMRI.

# Image Contrast

- Images can be produced that are sensitive primarily to $T_1$, $T_2$, or $T_2$*.
- Because $T_1$ and $T_2$ vary with tissue type, they are able to represent boundaries between CSF, gray and white matter.
- Because $T_2$* is sensitive to flow and oxygenation, it is can be used to image brain function.

# End of Module