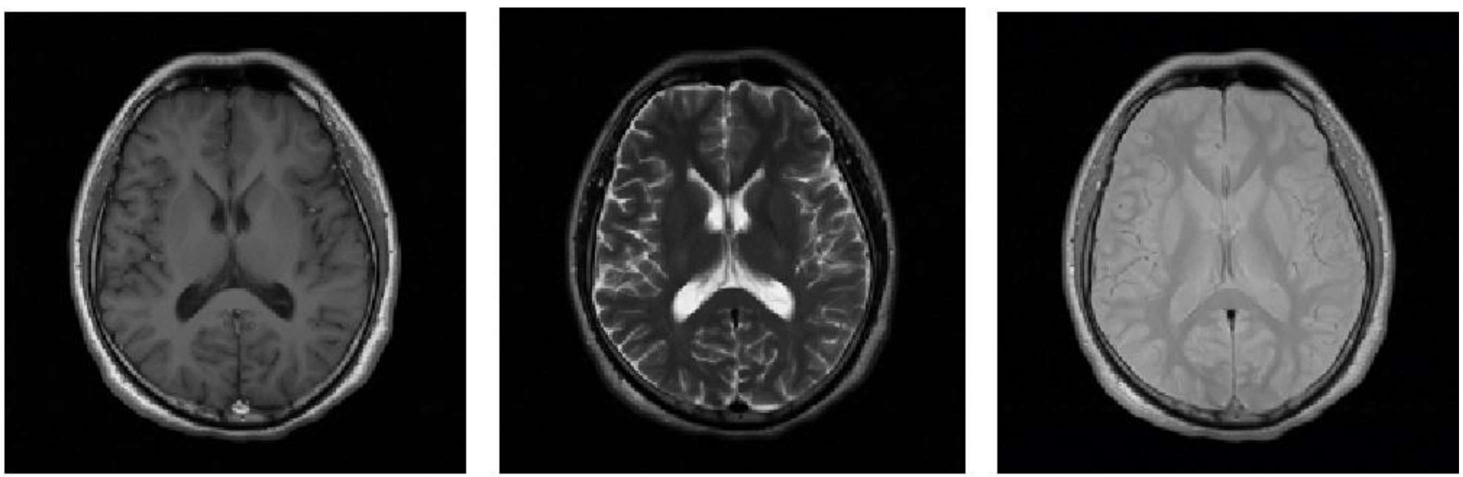
Tissue Characteristics
Module Three



T1 T2 PD

Equilibrium State

- Equilibrium State
  - At equilibrium, the hydrogen vector is oriented in a direction parallel to the main magnetic field.
  - Hydrogen atoms within the vector precess at a frequency predicted by the Larmor Equation and are slightly out of phase with each other.

Excited State

- Excited State
  - When the RF is turned on the protons precess in phase with one another.
  - The protons absorb the energy and tip the net magnetization out of the longitudinal plane into the transverse plane.

Back to Equilibrium

- Back to Equilibrium
  - When the RF pulse is turned off, the RF waves will be in-phase for a while in the transverse plane.
  - During the next few milliseconds, the stimulated protons will re-emit their absorbed energy causing transverse magnetization to decay.

Tissue Characteristics

– The decay occurs because the protons fall out-of phase with one another and give up their acquired energy over a specific period of time.
– Net magnetization also begins to return from the transverse plane back into the longitudinal plane.

Relaxation

- Relaxation
  - Relaxation is the return of the spin system to equilibrium following a RF pulse.
  - Equilibrium for the spin system is:
    - Longitudinal Magnetization
    - Spins out-of-phase

Energy Released

- Several things may happen to the energy that is released.

1. It may be released as a radio wave and recorded as the MR signal.
2. It may be lost irreversibly to the surrounding tissue "lattice" in the form of heat or induced molecular motion (T1 relaxation).
3. It may be transferred reversibly to other protons undergoing resonance, although phase uniformity may be lost (T2 relaxation).

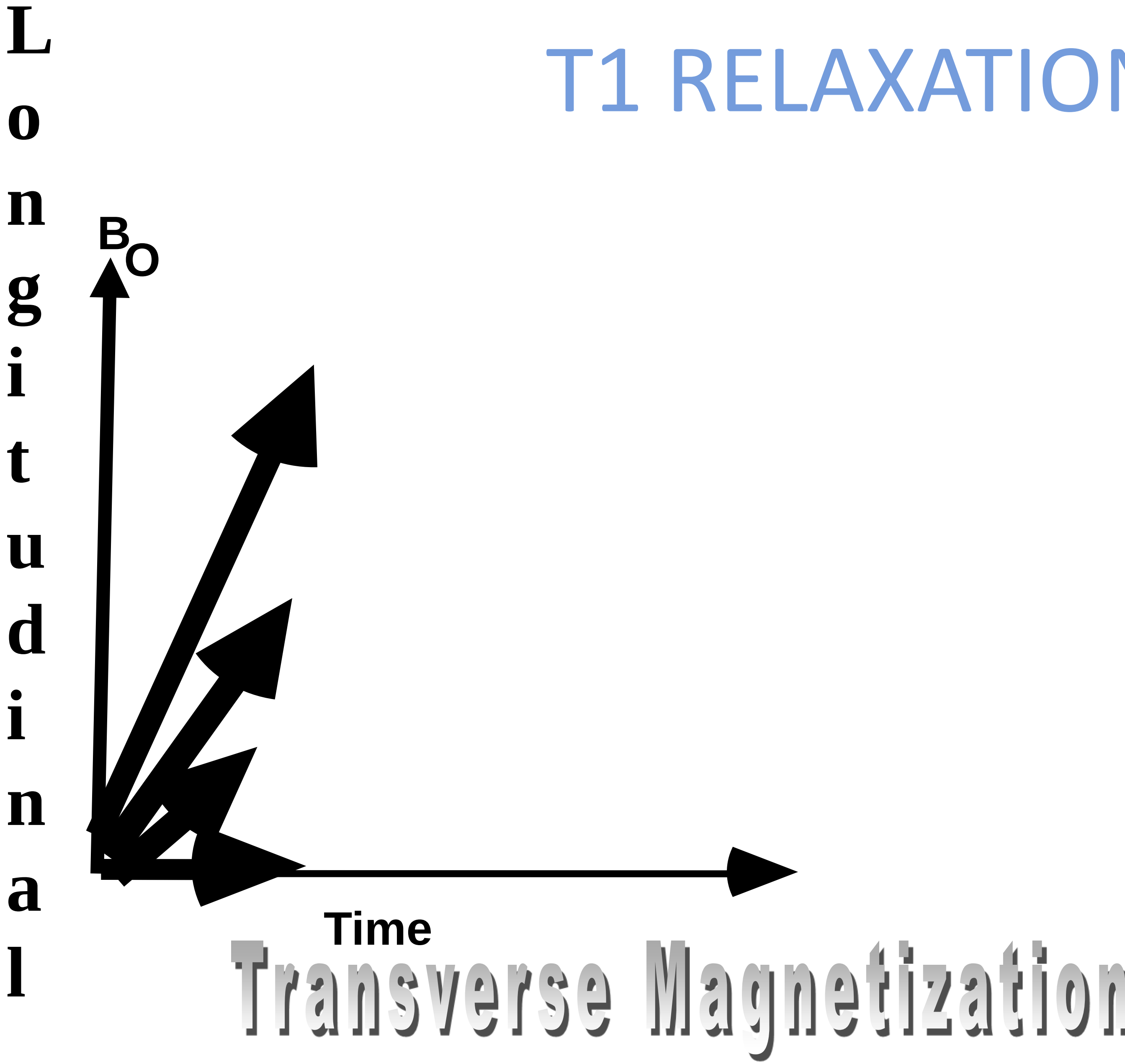
T1 Longitudinal Relaxation

- RF stimulation causes the nuclei to absorb energy, lifting them to an excited state.
- The nuclei in their excited state can return to the ground state only by dissipating their excess energy to the environment.
- This process is termed **T1 Longitudinal Relaxation.**

Spin Lattice Relaxation

- T1 relaxation time measures the time it takes the sample to become re-polarized (magnetized back to longitudinal plane) after being perturbed by a radio frequency pulse.
- Also called “Spin Lattice” Relaxation time.
- Also called “Thermal Relaxation” time.

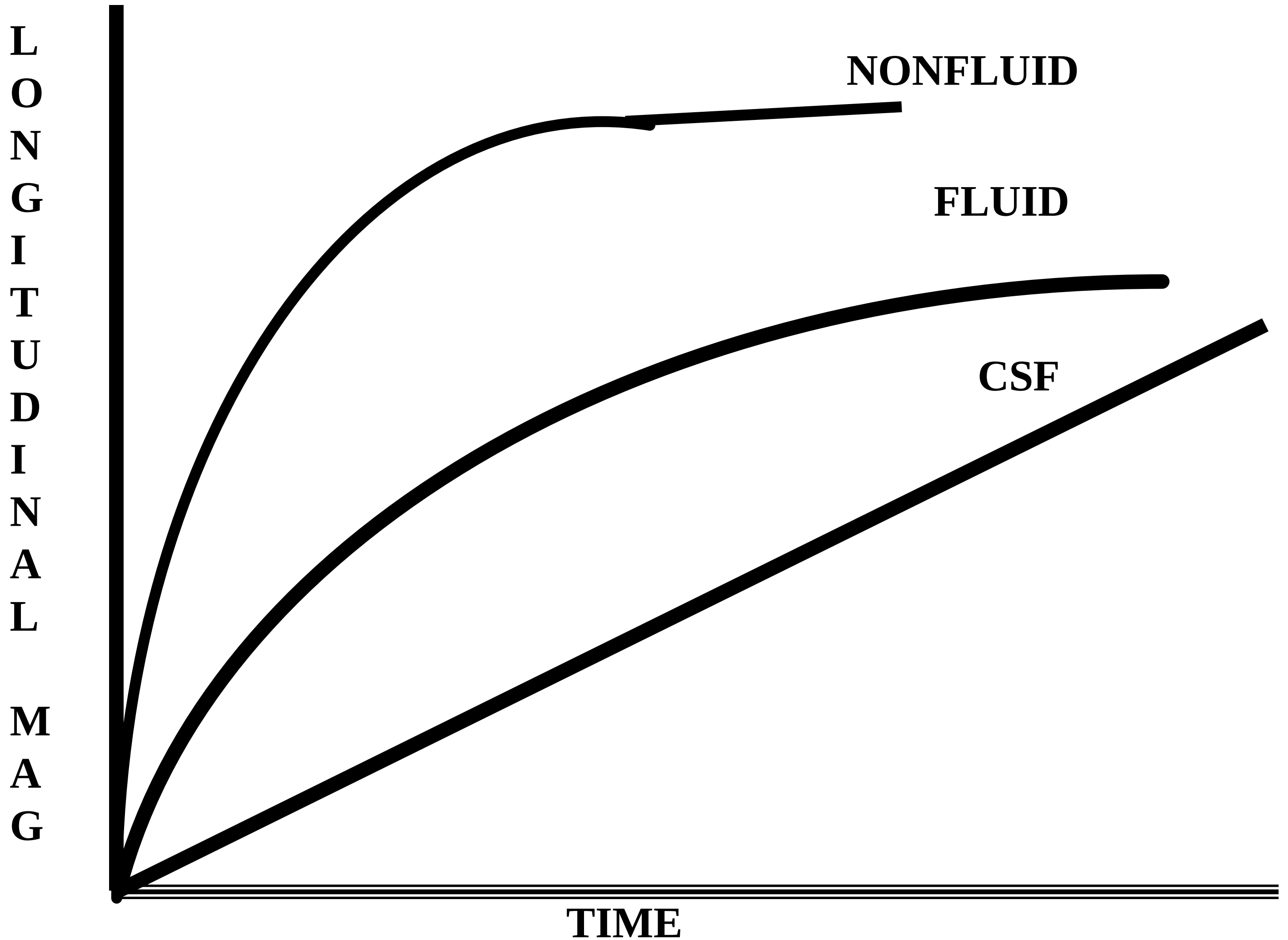
T1 RELAXATION



T1 Depends on:

- The molecular structure of the sample.
- It's physical state (liquid or solid).
  - Whether a sample is liquid or solid depends on whether the forces between molecules are fixed or fluctuating.
- The strength of the internal magnetic fields.
  - The presence and relative strengths of the internal magnetic fields affect the rates of response of the resonating nuclei to the external magnetic field.

T1 Exponential Growth Curve

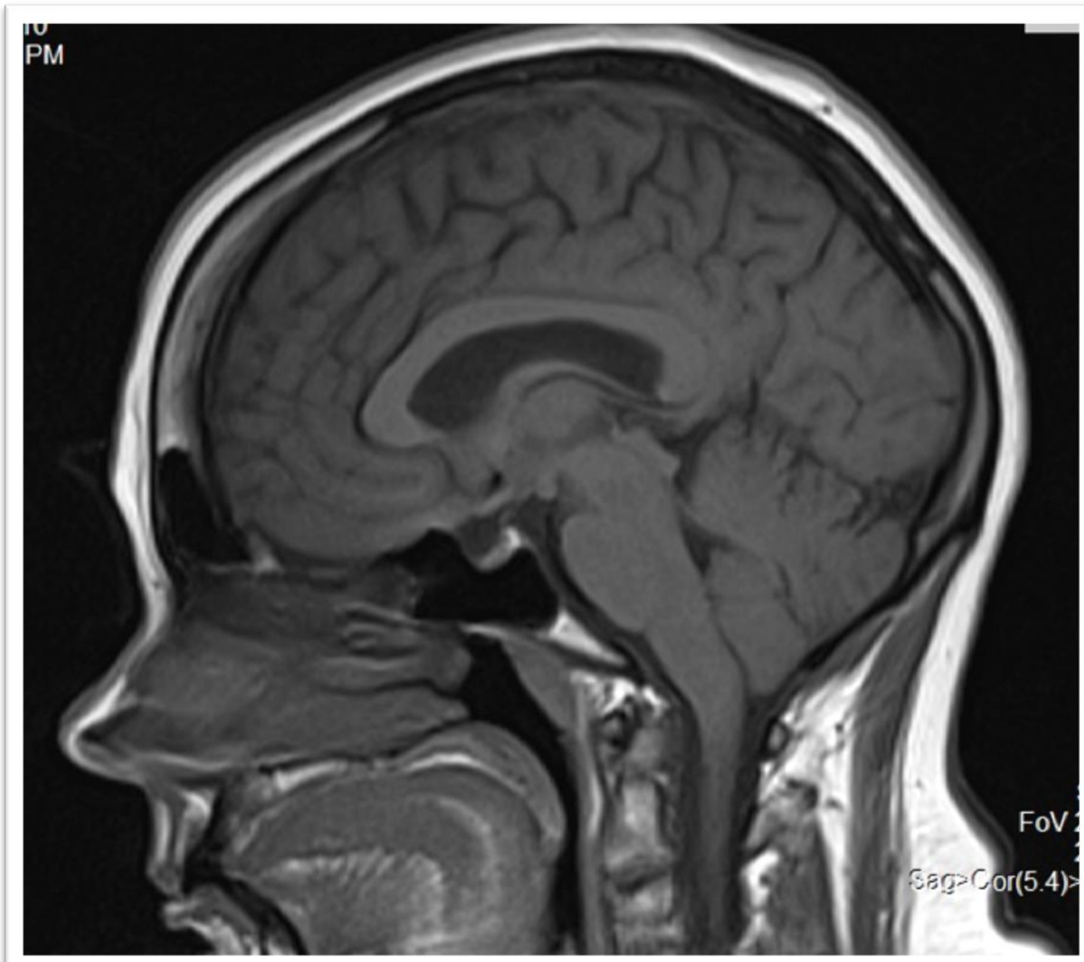


T1 Recovery

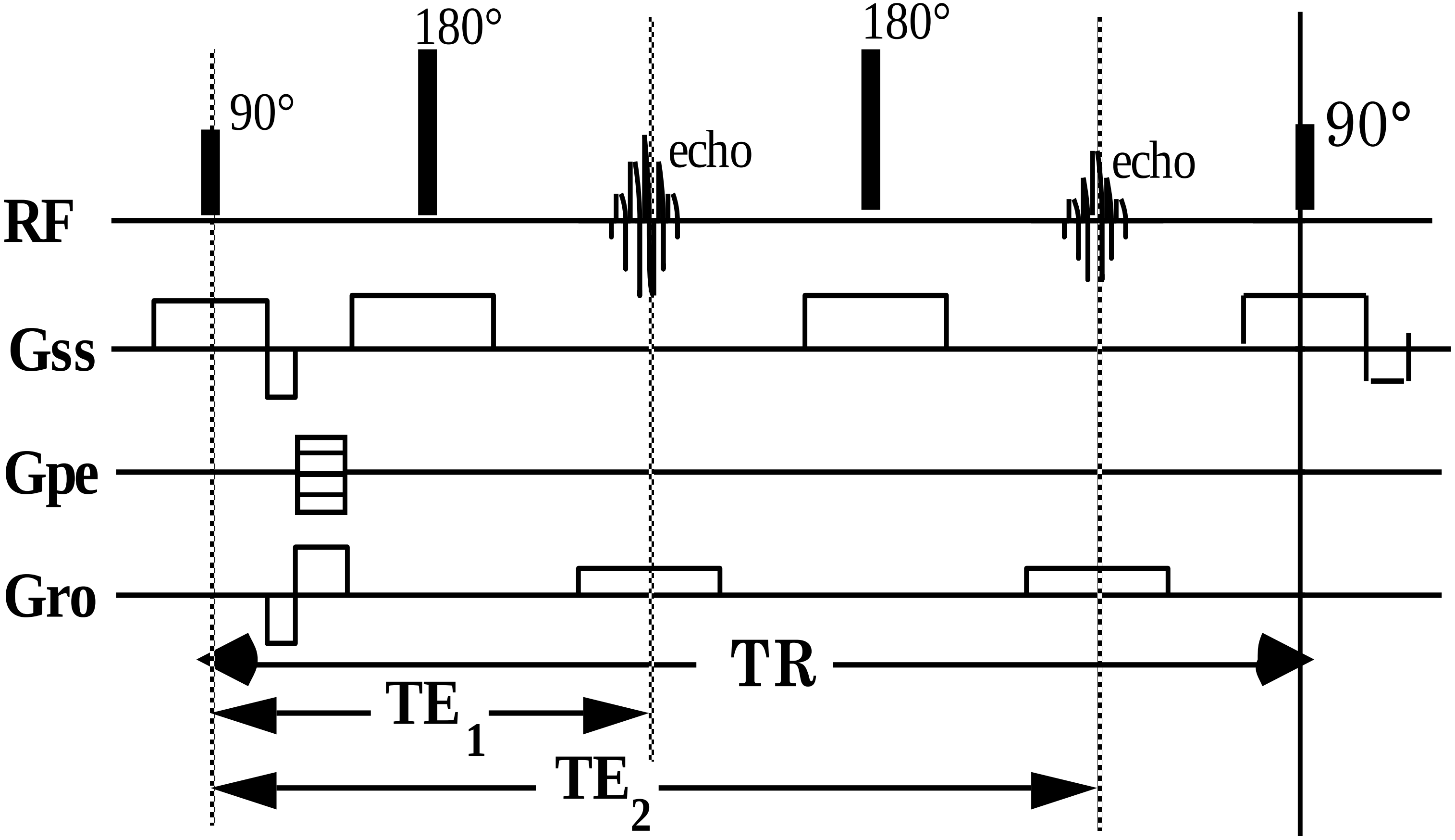
- $1T_1$ is the length of time it takes net magnetization to recover 63% of its full T_1 relaxation or recovery.

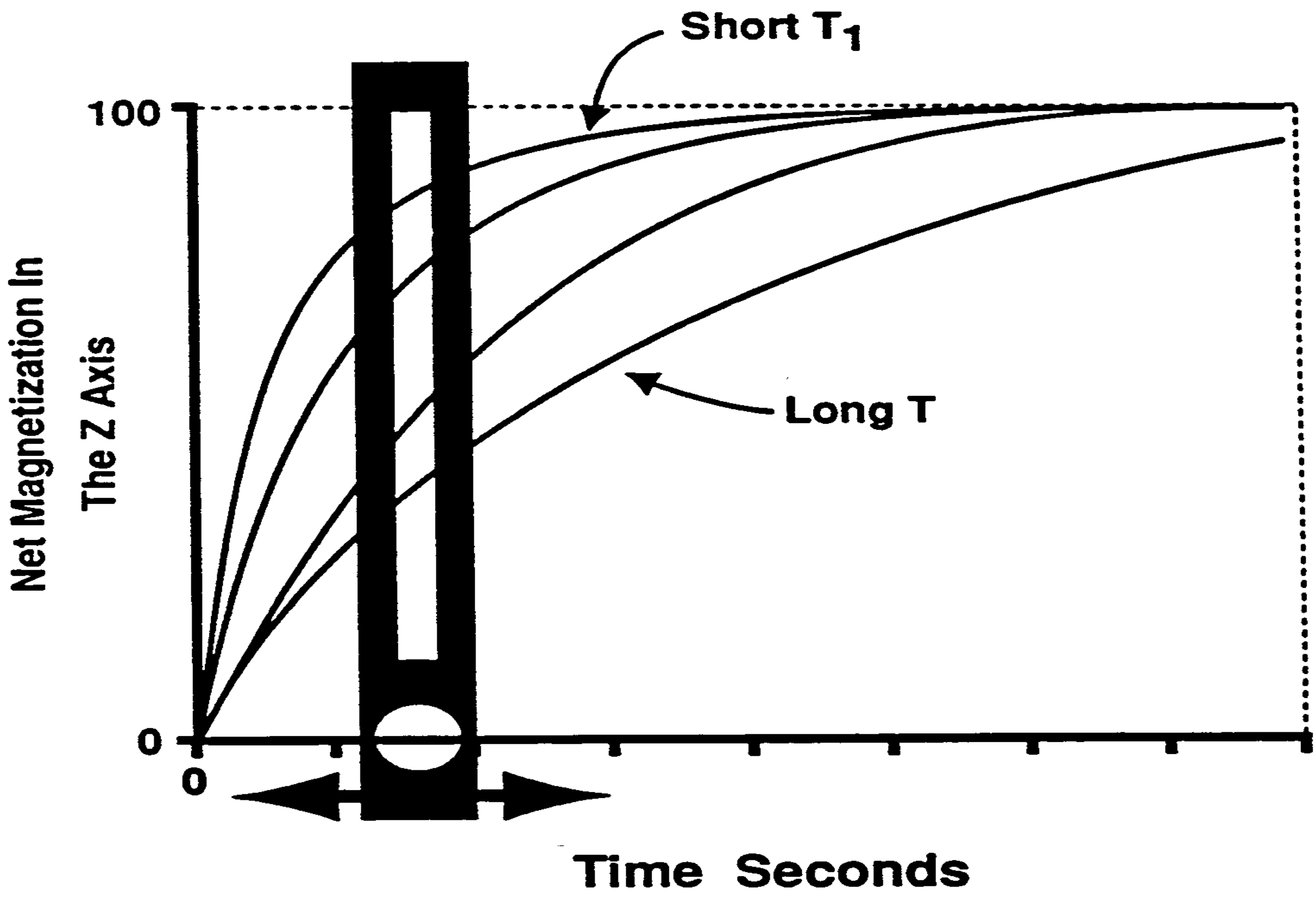
- It takes $5T_1$ for full recovery or 99% T_1 Growth.

T1-weighted image contrast



Dual Spin Echo Pulse Sequence





Short T_1
100
0
0
Net Magnetization In The Z Axis
Long T
Time Seconds

Mean T1 Relaxation Times in milliseconds (msec)

TISSUE	0.15T	0.35T	1.0T	1.5T
Fat	150	215	220	250
Liver	250	323	420	490
White Matter	300	539	680	783
Muscle	450	600	730	863
Spleen	400	554	680	778
Gray Matter	475	656	809	917
CSF	2000	2000	2500	3000

T1 Relaxation Summary

- T1 represents the response of the magnetized sample in an excited state after being perturbed with a unique resonant frequency.
- T1 represents the exponential time constant for re-polarization in a direction parallel to the external magnetic field Bo.
- Since longitudinal relaxation occurs by thermal interaction between molecules in lattice, T1 is also called the “longitudinal, thermal or spin-lattice” relaxation time.

T2 Transverse Relaxation

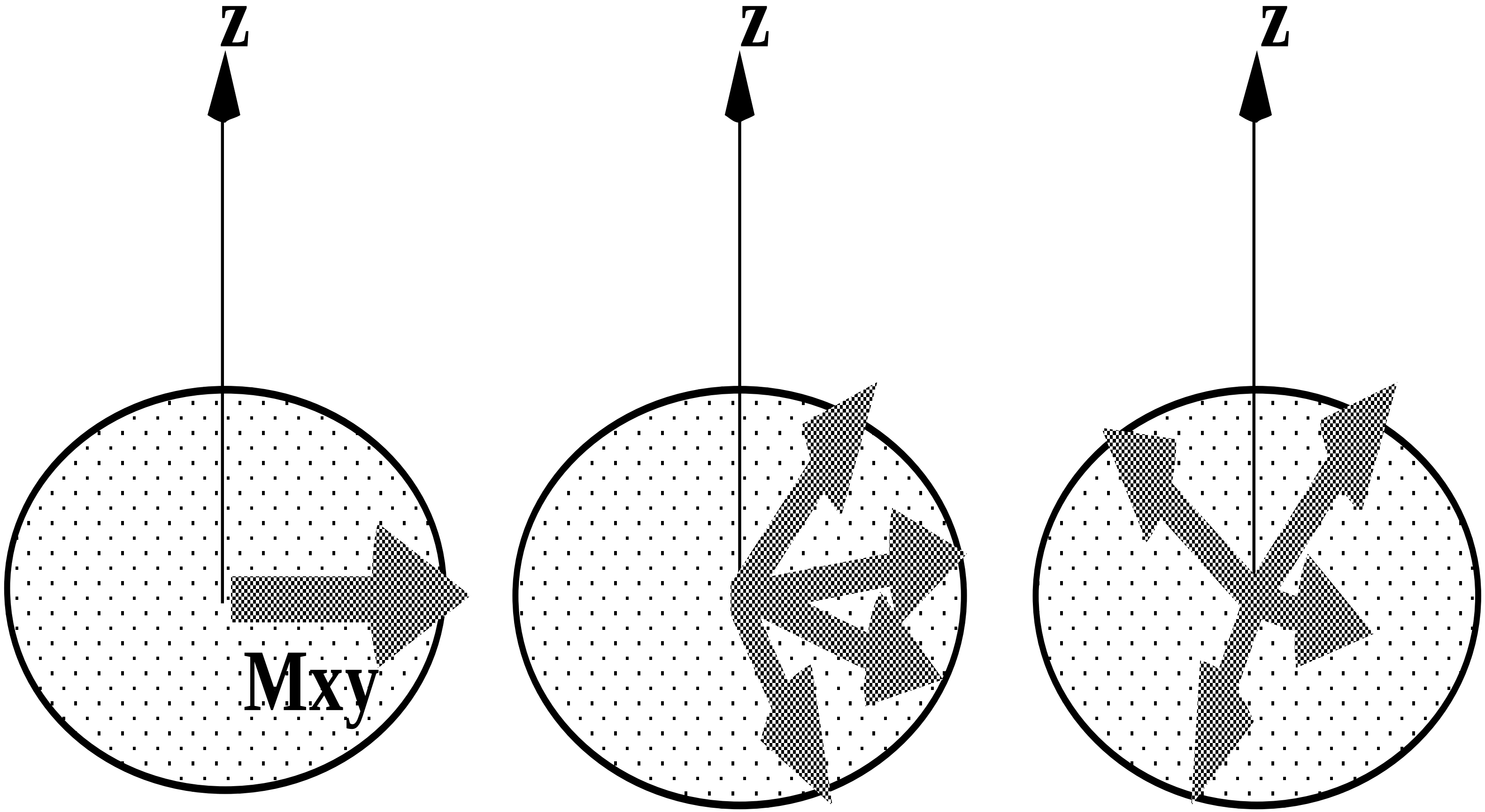
- In the T2 relaxation process, no energy is transferred from the nuclei to the lattice. Rather, the nuclei in the excited and ground state exchange energy with each other.

- While one nucleus absorbs energy, its neighbor releases it.

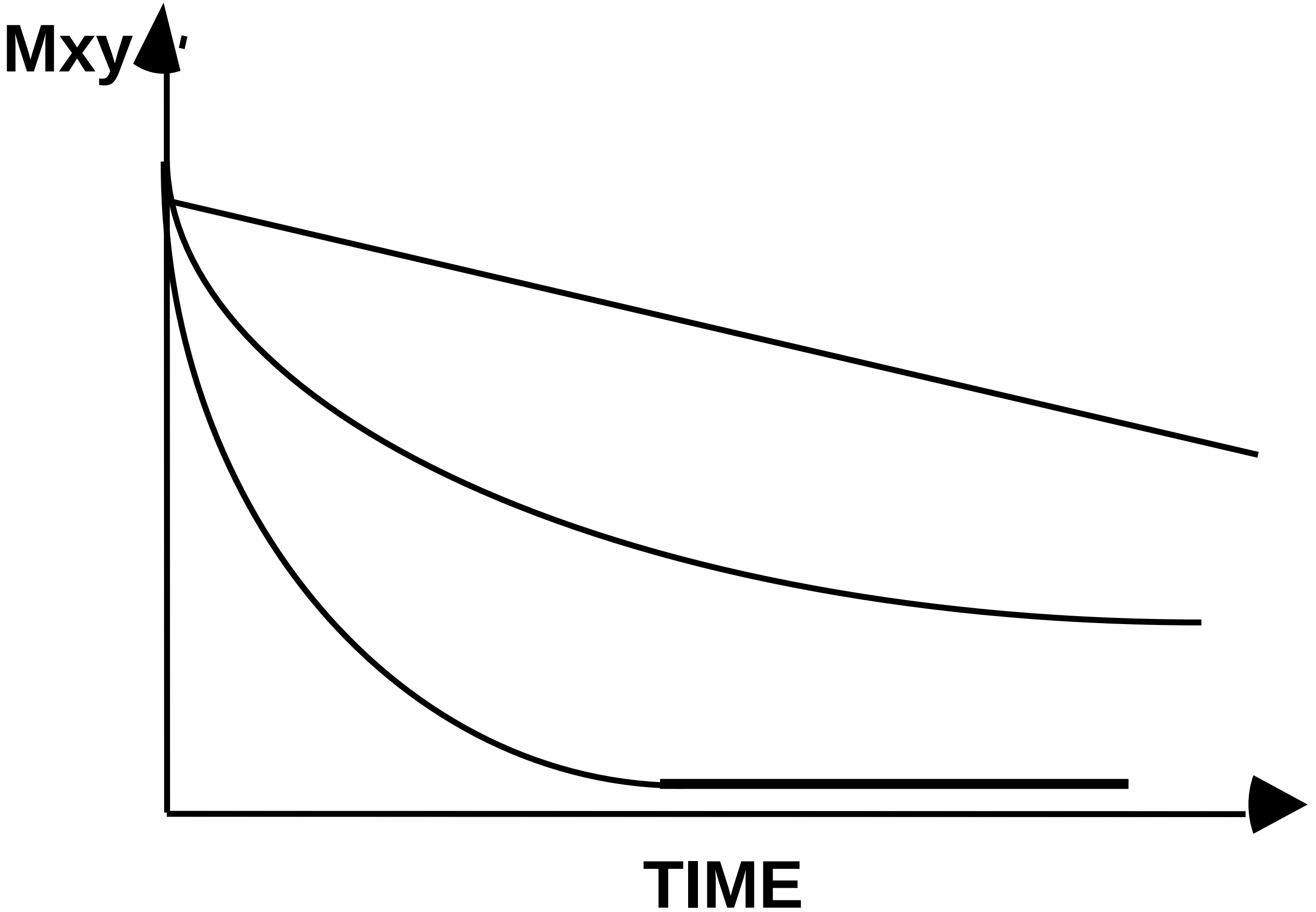
Spin-Spin Relaxation

- Also called “Spin-Spin” relaxation
- T2 measures how long the resonant nuclei hold the temporary transverse magnetization, Mxy.
- T2 Relaxation indicates the relationship between the strength of the external magnetic field Bo and the strength of the local internal fields.
- T2 interactions only result in a change of phase between resonating protons.

T2 Dephasing



T2 Exponential Decay Curve

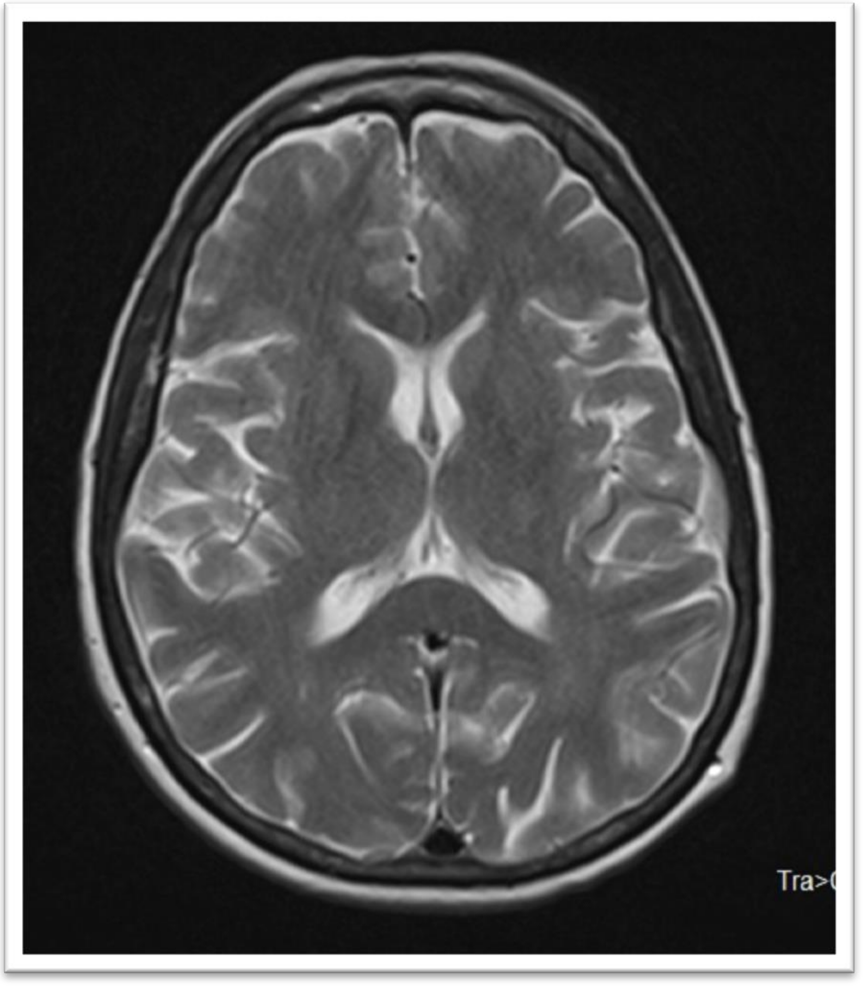


T_2 Decay

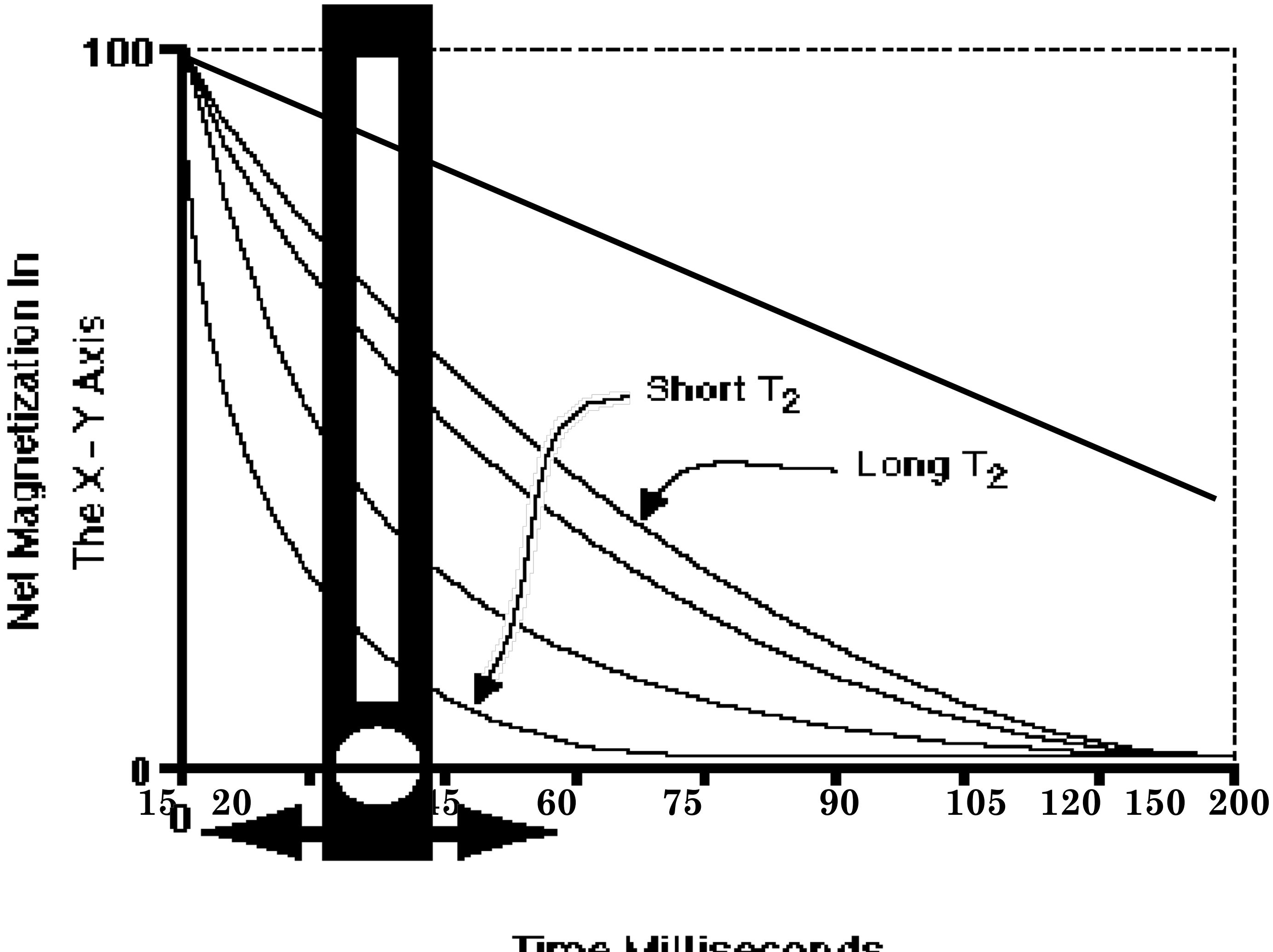
- $1T_2$ is the length of time it takes net magnetization to lose 63% of its net magnetization.

- It takes $5T_2$ for full T_2 decay.

T2-weighted image contrast



T2 / TE Dependent



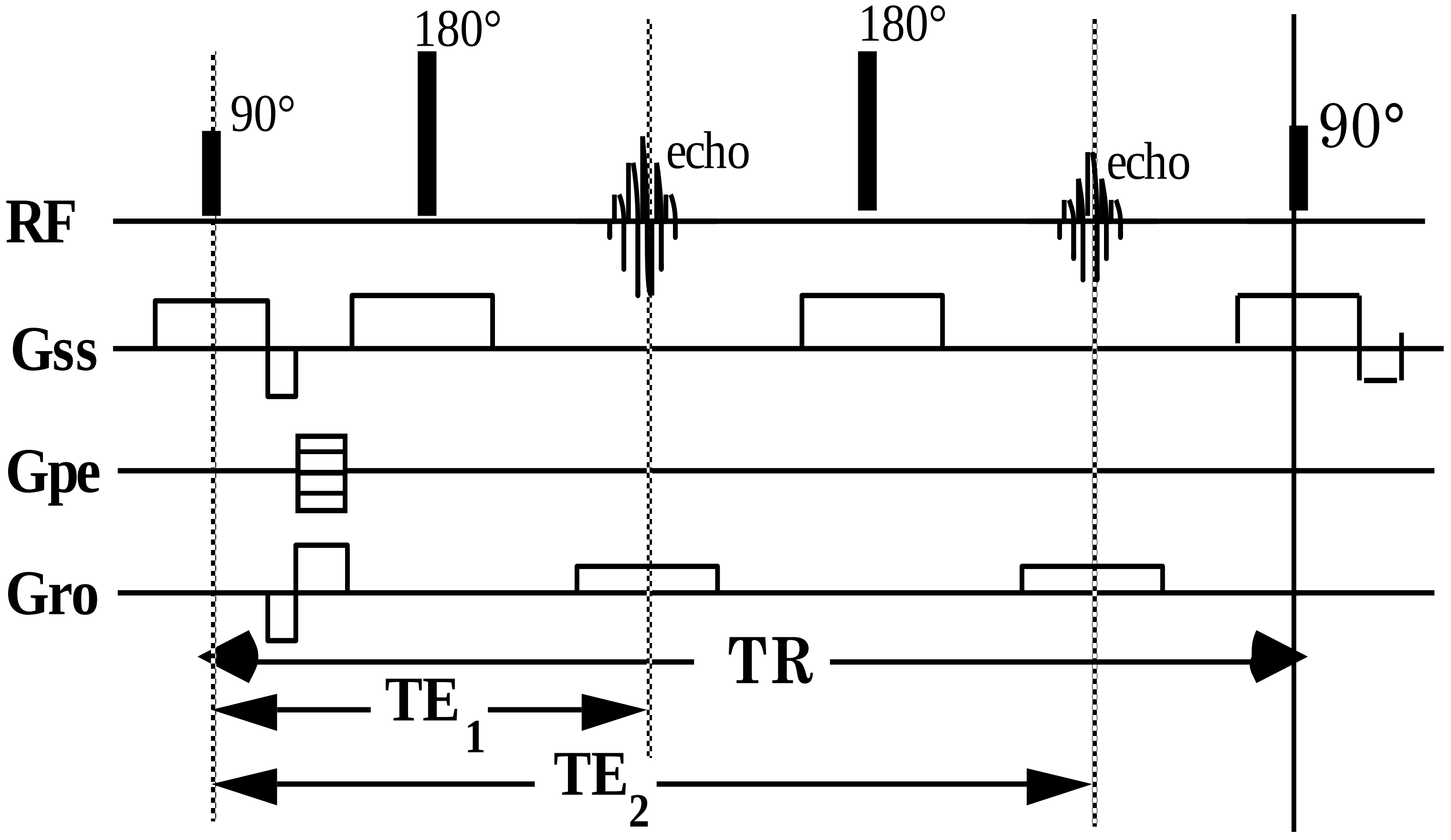
In Summary

- T2 represents the exponential time constant for decay of the transverse magnetization Mxy following an RF pulse.
- T2 represents the exchange of energy from one proton to another which causes dephasing.

T2 Relaxation Time (msec)

TISSUE	T2
Fat	85 msec
Liver	43 msec
Muscle	47 msec
White Matter	90 msec
Gray Matter	100 msec
CSF	300 msec

Dual Spin Echo Pulse Sequence



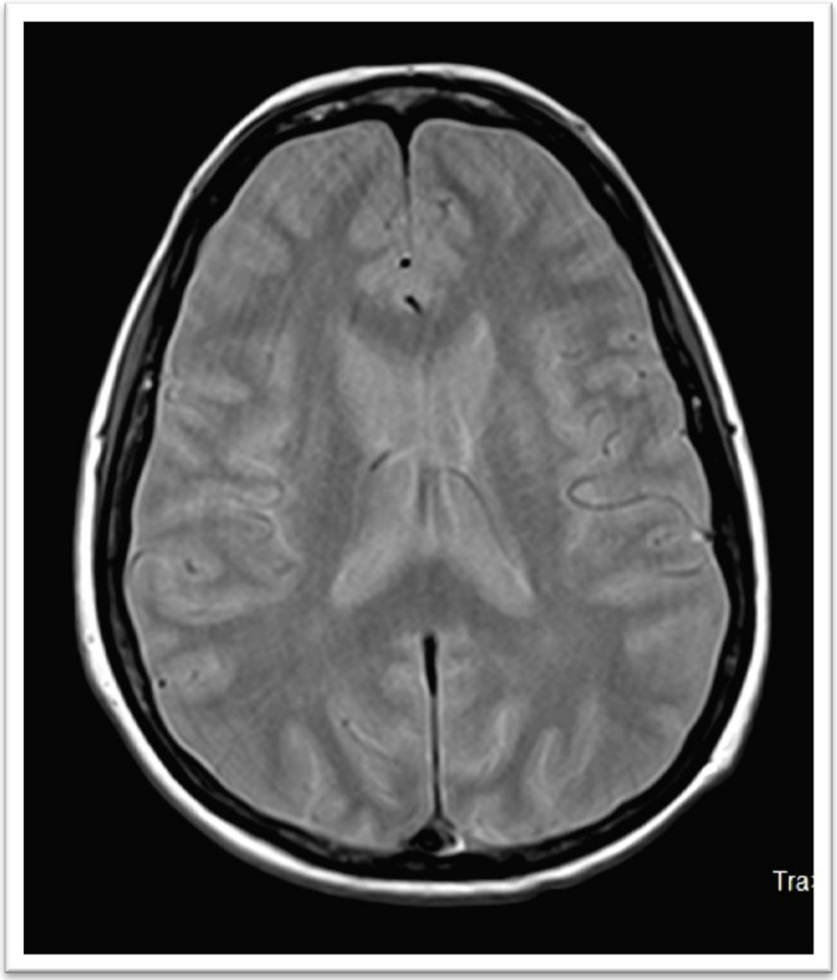
Proton Density

- Proton Density is a representation of the number of hydrogen protons that are in a given volume (voxel or pixel).
- The higher the number of protons the brighter the signal.
- Proton density is one of the major determinants of signal intensity.

Proton Density

- Also called Spin density and Hydrogen density
- CSF has the highest proton density and will be bright.
- Air, cortical bone has very low spin density and will appear as no MRI signal or very dark.
- All other tissues fall in between this spectrum.

Proton Density-weighted image Contrast



Tissue Contrast Parameters

Weighted Contrast	TR	TE
T1-weighted	short	short
T2-weighted	long	long
PD-weighted	long	short

Table of the Typical Appearances of Some Tissues in Different Image Weighting

Tissue Type		Weighting	
	Proton Density	T1-Weighted	T2-Weighted
Fat	Bright	Bright	Gray
Cortical Bone	Dark	Dark	Dark
Blood (fast flow)	Dark	Dark	Dark
Edema	Bright/Gray	Gray/Dark	Bright
Protein	Bright/Gray	Bright	Bright
Cerebral Spinal Fluid	Gray	Dark	Bright
Gray Matter	Isointense	Gray	Gray
White Matter	Gray/Dark	Bright	Dark
Spinal Cord	Intermediate Gray	Intermediate Gray	Gray
Vertebral Body	Intermediate Gray	Intermediate Gray	Intermediate Gray
Intervertebral Disk	Light gray	Gray	Bright
Meniscus	Dark	Dark	Dark
Ligament/Tendon	Dark	Dark	Dark
Hyaline Articular Cartilage	Bright	Bright	Gray
Fibrous Tissue (scar)	Dark	Dark	Dark
Muscle	Intermediate Gray	Intermediate Gray	Intermediate Gray
Bone Marrow	Intermediate Gray	Intermediate Gray	Intermediate Gray
Air	Dark	Dark	Dark

Contrast Characteristics of Pathology and Normal Anatomy

	T1-Weighted	T2-Weighted
Bright	Fat Hemangioma Intra-osseous lipoma Radiation Change Degenerative Fatty Deposition Methemoglobin Cysts with proteinaceous fluid Paramagnetic contrast agents Slow-flowing blood	CSF Synovial fluid Hemangioma Infection Inflammation Edema Some tumors Hemorrhage Slow-flowing blood Cysts
Dark/Gray	Cortical Bone Avascular Necrosis Infarction Infection Tumors Multiple Sclerosis Cysts Calcifications	Cortical Bone Bone islands Deoxyhemoglobin Hemosiderin Calcification T2 paramagnetic agents
Black	T1- and T2-Weighted	
	Air Fast Flowing Blood Ligaments Tendons Cortical Bone Scar tissue Calcification	