LECTURE 13 MAGNETIC RESONANCE PHYSICS

PHYSICS OF MRI (CHAPTER 12 OF PRINCE + LINKS)

POLARIZATION

RESONANCE

EXCITATION

SIMPLE EXPERIMENT

CONTRAST + RELAXATION

NEXT TIME: MR IMAGING (CHAPTER 13)

WHAT DOES MRI VISUALIZE?

MOSTLY ^1H IN H_2O (PROTONS)

ALSO ^1H IN LIPIDS, OTHER ORGANIC MOLECULES

VERY SENSITIVE PROBE OF TISSUE PROPERTIES

- TISSUE ORDER, STRUCTURE
- VELOCITY
- DIFFUSION
- TEMPERATURE
- O_2 SATURATION
- MANY MORE

OTHER NUCLEI

^{19}F, ^{13}C, ^{31}P, ^{15}N, ^{23}Na

LOWER SENSITIVITIES, CONCENTRATIONS THAN ^1H (PROTONS)

MRI IS RELATIVELY INSENSITIVE COMPARED TO

X-RAY, PET, CT

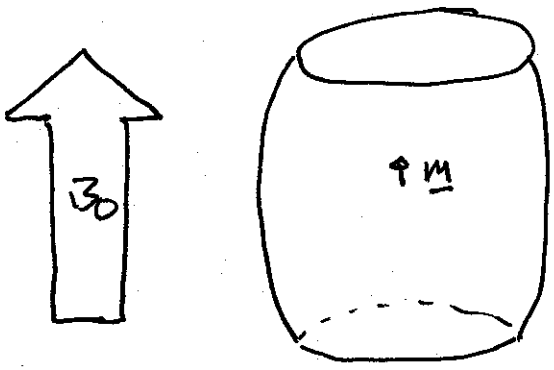
PET CAPTURES SINGLE EVENTS

X-RAY CAPTURES COUNTABLE NUMBER OF PHOTONS

MRI CAN SEE 1 mm^3 OF WATER ($\sim 10^{20}$ PROTONS)

POLARIZATION

IMMERSE OBJECT IN A STRONG MAGNETIC FIELD



$B_0 = 0.1\,T$ TO $20+\,T$

(EARTH'S FIELD $\cong 60\,\mu T$)

CLINICAL SYSTEMS

0.5 T TO 3T

$\underline{M} \sim 10^{-6} \times$ MAIN FIELD

LARGE B_0 PRODUCES TINY MAGNETIZATION $\underline{M}$

A FEW PARTS PER MILLION (PPM)

OBJECT (YOU!) IS MAGNETIZED

RESONANCE

MAGNETIZATION ABSORBS AND EMITS ENERGY AT A VERY SPECIFIC FREQUENCY

$\omega_0 = \gamma B_0$ $\quad$ γ = GYROMAGNETIC RATIO

$f_0 = \gamma B_0$ $\quad$ $\gamma = \frac{\gamma}{2\pi}$

FREQUENCY IS PROPORTIONAL TO B_0. LARMOR FREQUENCY

SOME IMPORTANT γ's ARE

NUCLEI	MHz/T	USE
^{1}H	42.586	WATER, ORGANIC MOLECULES
^{13}C	10.705	ORGANIC MOLECULES, 10% NATURAL ABUNDANCE
^{19}F	40.05	BLOOD SUBSTITUTES, DRUGS
^{31}P	17.235	ATP, ENERGY METABOLISM
^{15}N	-4.316	
^{23}Na	11.262	SODIUM, EDEMA, STROKE
^{3}He	-32.434	HYPERPOLARIZED, LUNG IMAGING
^{129}Xe	-11.777	HYPERPOLARIZED, LUNG, PERFUSION

RESONANCE IS SIGNED. MOST NUCLEI PRECESS IN LEFT HAND SENSE (POSITIVE GAMMA).

SENSITIVITY DEPENDS ON

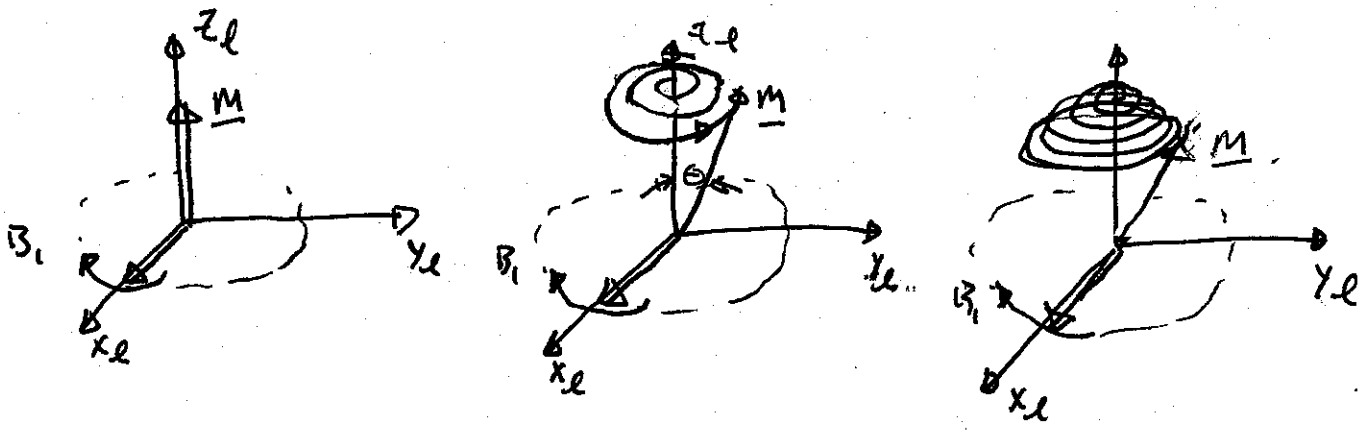
γ (FREQUENCY)

ABUNDANCE (HOW MUCH THERE IS)

POLARIZATION (WHAT FRACTION IS POLARIZED)

EXCITATION

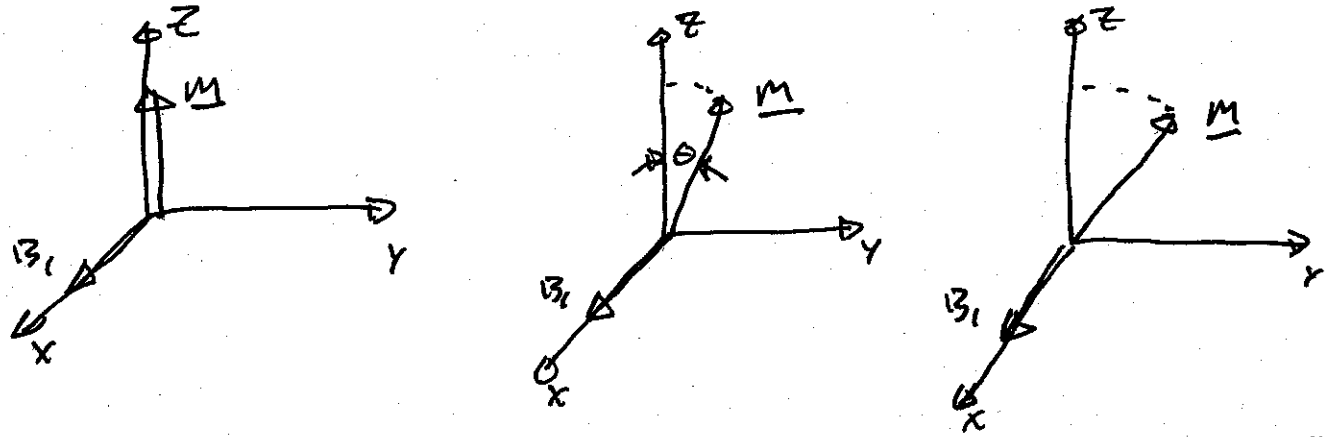
AS RF ENERGY IS APPLIED AT THE LARMOR FREQUENCY, M TIPS AWAY FROM B_0



B_1 ROTATES AT ω_0, M PRECESSES AT ω_0

ANGLE FROM Z AXIS, θ, SLOWLY INCREASES

IF WE IMAGINE WE ARE SITTING ON A COORDINATE AXIS THAT IS ROTATING AT ω_0, WHAT WE WOULD SEE IS



ROTATING FRAME

IN LAB FRAME

EVERYTHING IS ROTATING AT ω_0

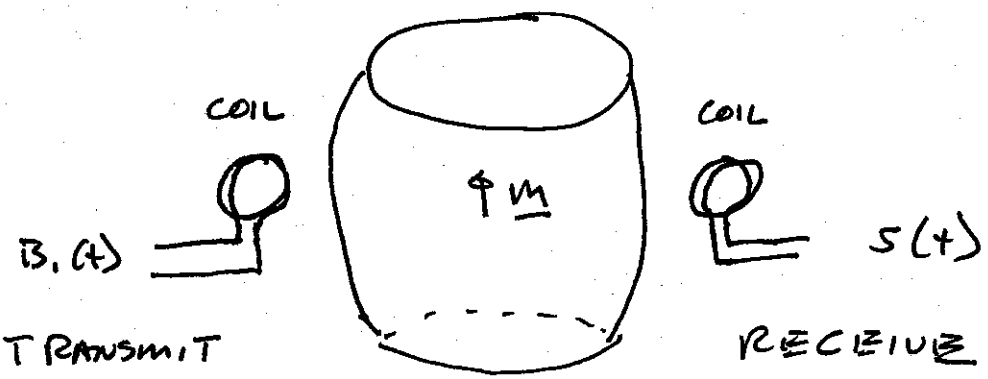
IN ROTATING FRAME AT ω_0

B_1 IS FIXED

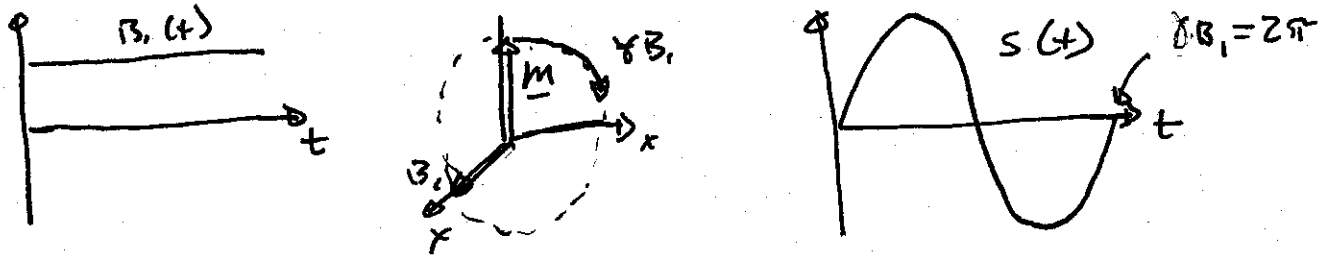
$\underline{M}$ PRECESSES (SLOWLY) AROUND B_1

MUCH SIMPLER TO UNDERSTAND

SIMPLE EXPERIMENT



ROTATING FRAME



EXCITATION ANGLE

$$\Theta(t) = \gamma \int_0^t B_1(s)\, ds$$

EXAMPLE

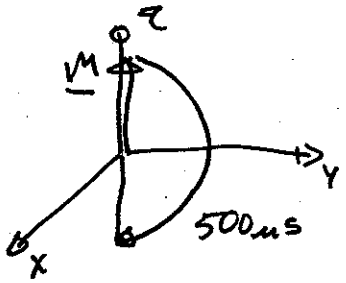
a) HOW LONG DOES IT TAKE TO INVERT THE MAGNETIZATION?

THIS IS AN EXCITATION ANGLE OF π, SO

$$\pi = \gamma B_1 t$$

$$t = \frac{\gamma B_1}{\pi} = \frac{\gamma}{2} B_1$$

b) ON A CLINICAL MRI SYSTEM, THIS TAKES 500ms. HOW FAST IS $\underline{M}$ ROTATING ABOUT B_1



$\frac{1}{2}$ CYCLE IN 500ms

1 CYCLE IN 1ms

$\Rightarrow$ 1KHZ

c) WHAT MAGNETIC FIELD IS B_1?

$$f = \gamma B_1$$

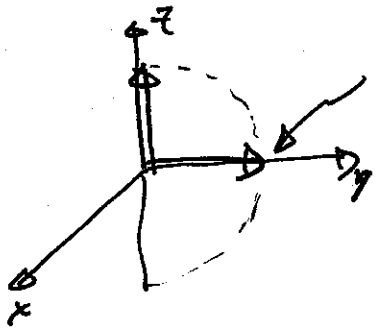
$$1\text{KHz} = 42.57 \left(\text{MHz}/\text{T}\right)\left(\frac{1000\text{ KHz}}{\text{MHz}}\right) B_1$$

$$B_1 = 23\mu\text{T}$$

THIS IS ON THE ORDER OF THE EARTH'S FIELD!

MUCH SMALLER THAN B_0.

d) ONLY THE x-y COMPONENT OF $\underline{M}$ IS DETECTABLE. WHAT Θ MAXIMIZES THE SIGNAL?



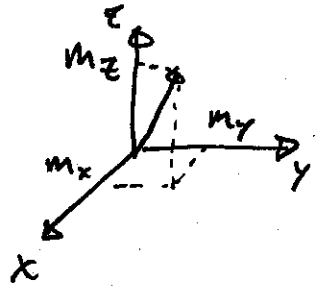
MAXIMUM AT $\Theta = \frac{\pi}{2}$

THIS IS AN EXCITATION PULSE.

MAGNETIZATION COMPONENTS

MAGNETIZATION $\underline{M}$ IS A VECTOR

$$\underline{M} = (m_x, m_y, m_z)$$



LONGITUDINAL MAGNETIZATION IS m_z

TRANSVERSE MAGNETIZATION IS m_x, m_y

OFTEN WRITTEN AS

$$m_{xy} = m_x + i\, m_y$$

RELAXATION

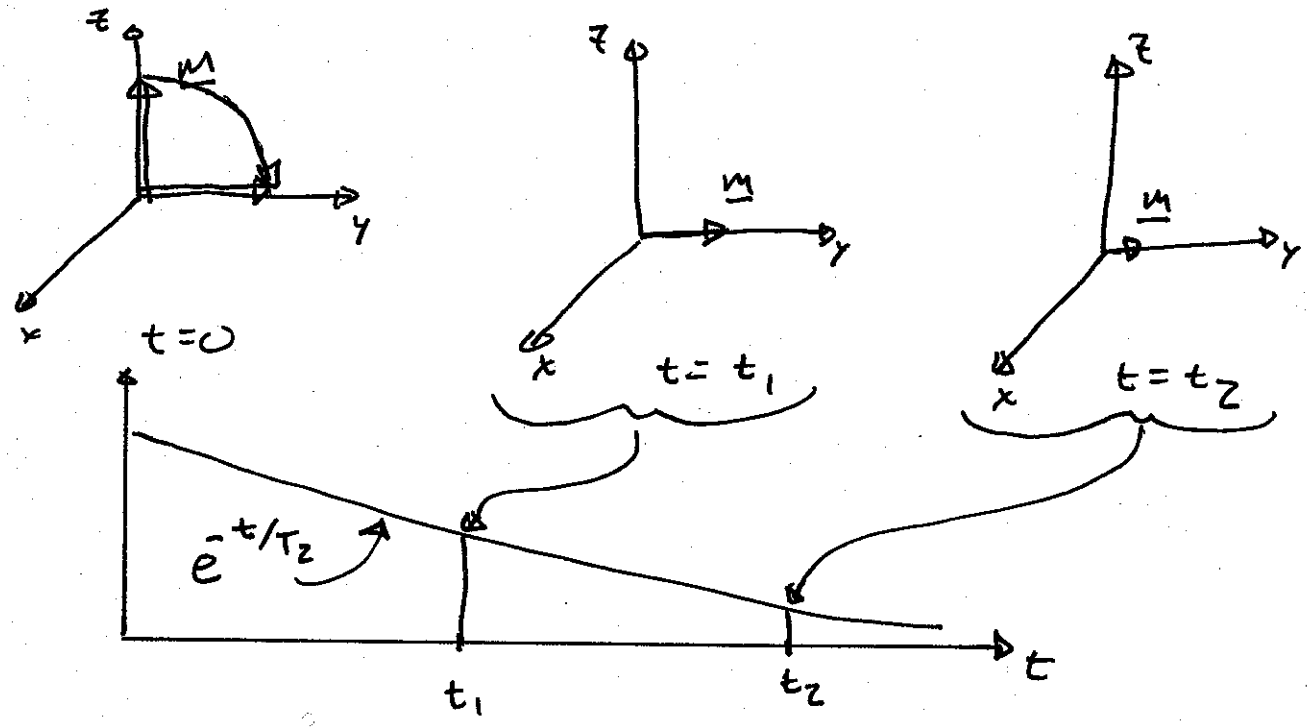
AFTER $\underline{M}$ IS EXCITED

TRANSVERSE MAGNETIZATION DECAYS (T_2)

LONGITUDINAL MAGNETIZATION RECOVERS (T_1)

T_2 DECAY

AFTER EXCITATION



TRANSVERSE SIGNAL DECAYS EXPONENTIALLY

CALLED "FREE INDUCTION DECAY" OR FID

T_2 IS DUE TO LOW FREQUENCY INTERACTIONS

SPIN-SPIN INTERACTIONS

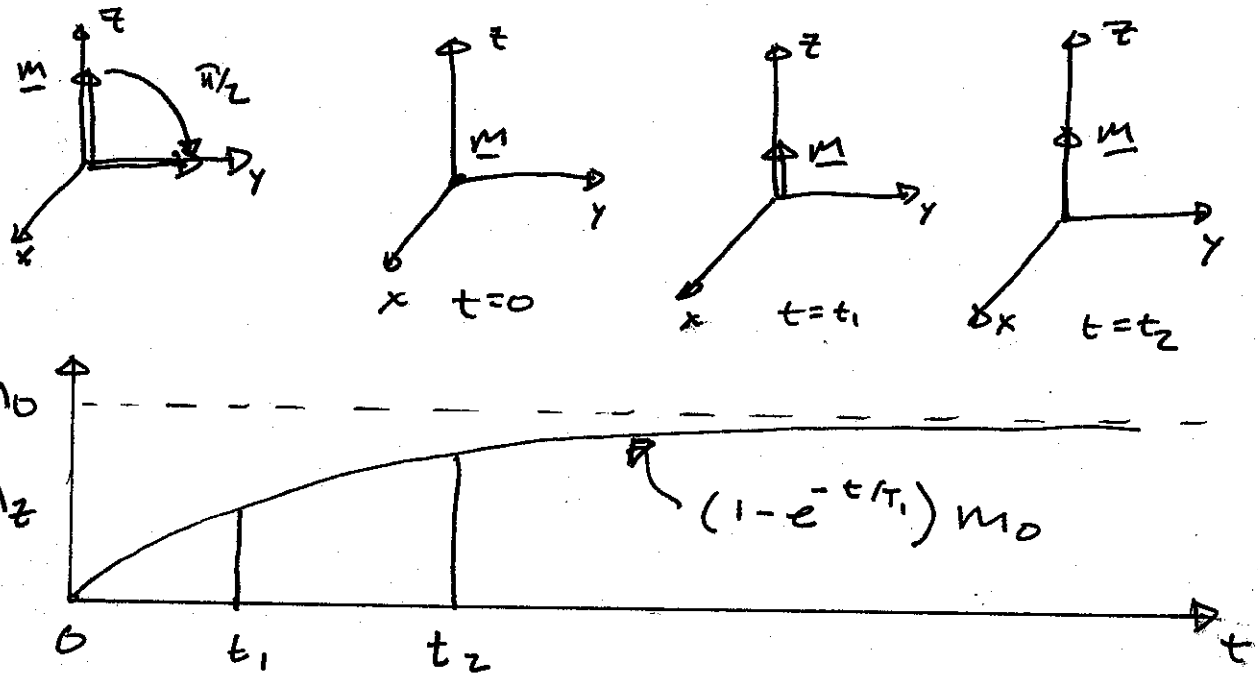
CHEMICAL EXCHANGE

DIFFUSION

O_2 SATURATION

T_1 RECOVERY

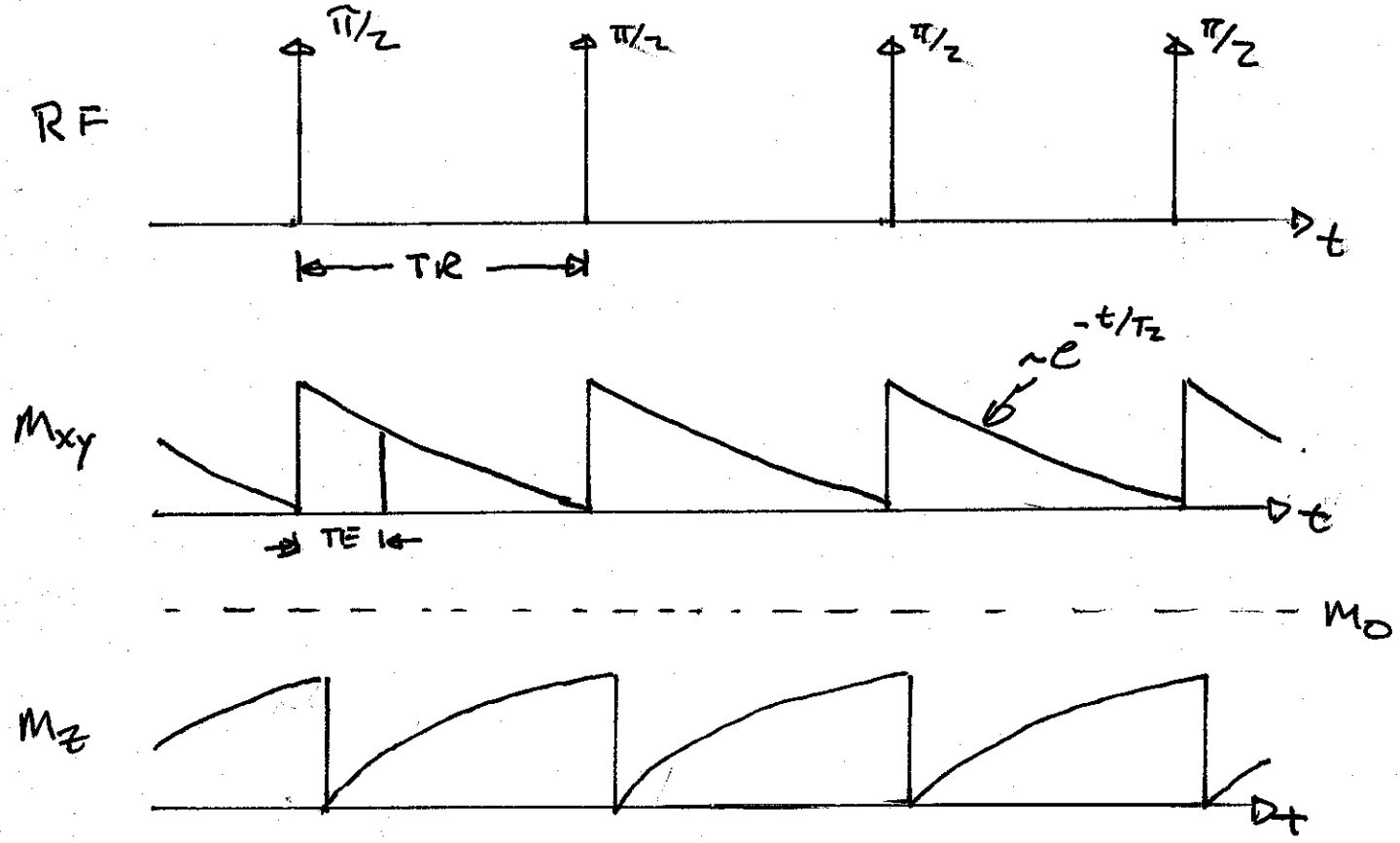
IF $T_2 \ll T_1$, THEN AFTER EXCITATION



LONGITUDINAL MAGNITIZATION RECOVERS TO EQUILIBRIUM DUE TO HIGH FREQUENCY INTERACTION WITH ENVIRONMENT MOLECULAR TUMBLING (LATTICE) CALLED SPIN-LATTICE RELAXATION

GENERATING MRI CONTRAST

MRI USES A PULSE SEQUENCE TO GENERATE CONTRAST



EXCITATION PULSES REPEATED EVERY TR

PARTIAL M_z RECOVERY GIVES T_1 CONTRAST

DELAY AFTER EXCITATION GIVES T_2 CONTRAST

THIS EXAMPLE WILL HAVE CONTRAST DUE TO

M_0, T_1, AND T_2

QUESTIONS

WHAT TR AND TE WOULD GIVE YOU

a) PURE M_0 CONTRAST (PROTON DENSITY)

b) PURE T_2 CONTRAST

c) PURE T_1 CONTRAST