LAST TIME:

- WE TALKED ABOUT GRADIENT FIELDS ALLOWING US TO SPATIALLY VARY FREQUENCY: G_x, G_y, G_z } $B_z = B_0 + G_x x + G_y y + G_z z$
- B_1 RF FIELD → LET'S US "EXCITE" OR "TIP" SPINS
- MAIN FIELD B_0 → SETS LARMOR FREQUENCY, ALWAYS IN Z DIRECTION.
- WE ALSO INTRODUCED THE BASIC 2D PULSE SEQUENCE 2DPR AND THE CONCEPT OF "SLICE SELECTION".
- WE INTRODUCED A BASIC "PULSE SEQUENCE DIAGRAM"
  - PULSE SEQUENCE DIAGRAM DESCRIBES WHAT IS HAPPENING WITH THE RF, GRADIENTS, AND ADC (OR SIGNAL SAMPLING) OVER TIME
- TODAY WE RETURN TO SOME BASIC MR PHYSICS.

THE BLOCH EQUATION:

IN GENERAL, THE BEHAVIOR OF THE MAGNETIZATION VECTOR $\vec{M}$ OF A SPIN SYSTEM (SAY A GIVEN VOXEL) IS DESCRIBED BY THE BLOCH EQUATION:

$$\frac{d\vec{M}}{dt} = \vec{M} \times \gamma \vec{B} - \frac{M_x \hat{i} + M_y \hat{j}}{T_2} - \frac{(M_z - M_0)\hat{k}}{T_1}$$

- $\vec{M} \times \gamma \vec{B}$: PRECESSION
- $\frac{M_x \hat{i} + M_y \hat{j}}{T_2}$: T_2 DECAY OF SIGNAL
- $\frac{(M_z - M_0)\hat{k}}{T_1}$: T_1 RECOVERY OF SIGNAL

- LET'S LOOK AT EACH TERM.

PRECESSION:

- AT THERMAL EQUILIBRIUM, $\vec{M}$ AND $\vec{B}$ WILL POINT IN THE SAME DIRECTION, SO:

$$\vec{M} \times \gamma \vec{B} = 0$$

- IF $\vec{M}$ IS MADE TO POINT IN A DIFFERENT DIRECTION THAN $\vec{B}$, PRECESSIONAL BEHAVIOR OF THE MAGNETIZATION WILL OCCUR.

- FROM CLASSICAL MECHANICS, THE TORQUE APPLIED TO A DIPOLE MOMENT $\vec{\mu}$ IN THE PRESENCE OF $\vec{B}$ IS:

$$\text{TORQUE} = \vec{\mu} \times \vec{B}$$

$\Uparrow$

RATE OF CHANGE OF ANGULAR MOMENTUM VECTOR $\vec{\Phi}$

$$\frac{d\vec{\Phi}}{dt} = \vec{\mu} \times \vec{B}$$

RECALL THAT $\vec{\mu} = \gamma \vec{\Phi}$, SO WE CAN WRITE:

($\vec{\mu}$: DIPOLE (MAGNETIC MOMENT))

$$\gamma \frac{d\vec{\Phi}}{dt} = \gamma \vec{\mu} \times \vec{B}$$

OR:

$$\frac{d\vec{\mu}}{dt} = \vec{\mu} \times \gamma \vec{B}$$

SUMMING EACH DIPOLE OVER THE SPIN SYSTEM ($\vec{M} = \sum_{n=1}^{N_S} \vec{\mu}_n$):

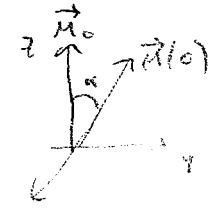
$$\boxed{\frac{d\vec{M}}{dt} = \vec{M} \times \gamma \vec{B}}$$

$\Leftarrow$ FIRST TERM IN BLOCH EQUATION $\Rightarrow$ PRECESSION!

ASSUME $\vec{B}(t) = B_0 \hat{k}$ (AFTER EXCITATION) AND THAT WE'VE

($\vec{B}(t) = B_0 \hat{k}$: STATIC IN Z DIRECTION)

"TIPPED" $\vec{M}$ AWAY FROM $\vec{M}_0$ BY ANGLE α:



PRECESSION AT $\omega = -\gamma B_0$!!

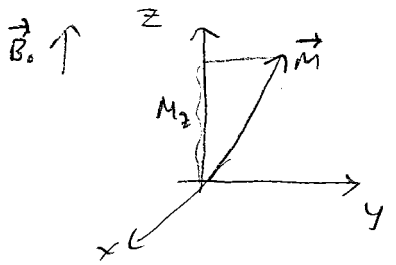
SOLUTION IS:

$$\vec{M}(t) = M_0 \sin\alpha \left[\sin(-\gamma B_0 t)\,\hat{i} + \cos(-\gamma B_0 t)\,\hat{j}\right] + M_0 \cos\alpha\, \hat{k}$$

RELAXATION: ← WE'RE ONLY GOING TO CONSIDER MAGNETIC DIPOLE-DIPOLE INTERACTIONS.

- NOW THAT WE'VE DESCRIBED PRECESSION, LET'S LOOK AT THE OTHER TERMS OF THE BLOCH EQN.

- FIRST, SOME DEFINITIONS:



M_z = LONGITUDINAL MAGNETIZATION

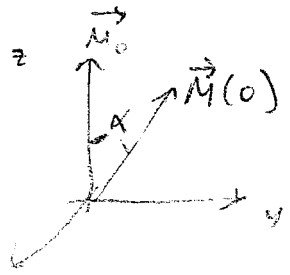
M_{xy} = TRANSVERSE MAGNETIZATION

LONGITUDINAL RELAXATION:

FROM BLOCH EQN: (IGNORING PRECESSION!)

$$\frac{dM_z}{dt} = -\frac{(M_z - M_0)}{T_1}$$

AFTER A TIP BY ANGLE α:



SOLUTION IS:

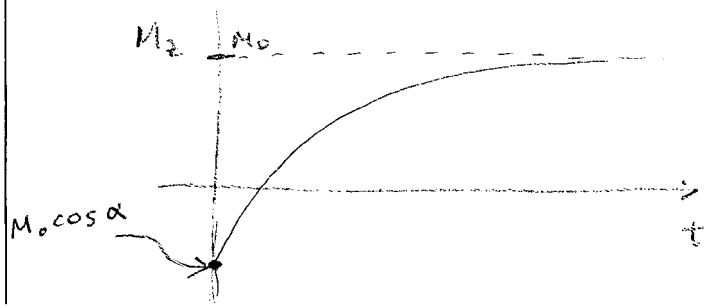
$$M_z = M_0 + \underbrace{[M_0 \cos\alpha - M_0]}_{M_z(0)} e^{-t/T_1}$$

FOLLOWING AN $\alpha = 90°$ TIP:

$$M_z = M_0 - M_0 e^{-t/T_1} = M_0(1 - e^{-t/T_1})$$

FOLLOWING AN $\alpha = 180°$ TIP:

$$M_z = M_0 + [-M_0 - M_0] e^{-t/T_0} = M_0 - 2M_0 e^{-t/T_0}$$



T_1 ⇒ "SPIN-LATTICE" TIME CONSTANT

CHARACTERIZES RETURN TO EQUILIBRIUM IN z DIRECTION

TRANSVERSE RELAXATION:

$$\frac{dM_{xy}}{dt} = -\frac{M_{xy}}{T_2}$$

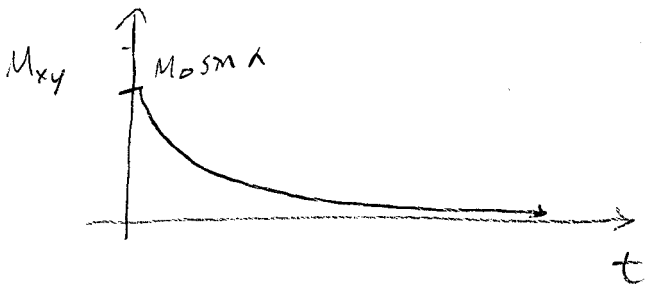
FROM BLOCH EQN, IGNORING PRECESSION!

AFTER A TIP BY α:

$$M_{xy} = M_0 \sin\alpha \, e^{-t/T_2}$$

- REMEMBER THAT OUR MR SIGNAL IS PROPORTIONAL TO M_{xy} (SINCE OUR RF COIL IS ORIENTED SO IT IS SENSITIVE IN THE xy PLANE, AND PRECESSION OCCURS AT OUR RF FREQUENCY IN THE xy PLANE ABOUT THE z AXIS!)

SO: T_2 IS A SIMPLE EXPONENTIAL SIGNAL DECAY!



$T_2 \Rightarrow$ "SPIN-SPIN" TIME CONSTANT

CHARACTERIZES DECAY OF TRANSVERSE MAGNETIZATION.

T_1 INCREASES W/ FIELD STRENGTH!

SOME BIOLOGICAL TISSUES:

	T2 (ms)	T1 (AT 1.5 T) (ms)
GRAY MATTER	100	920
WHITE MATTER	92	780
MUSCLE	47	870
FAT	85	270
KIDNEY	58	650
LIVER	43	495

CHEMICAL SHIFT:

- SMALL DISPLACEMENT OF RESONANT FREQUENCY DUE TO SHIELDING CREATED BY THE ORBITAL MOTION OF SURROUNDING ELECTRONS IN RESPONSE TO $\vec{B}_0$.

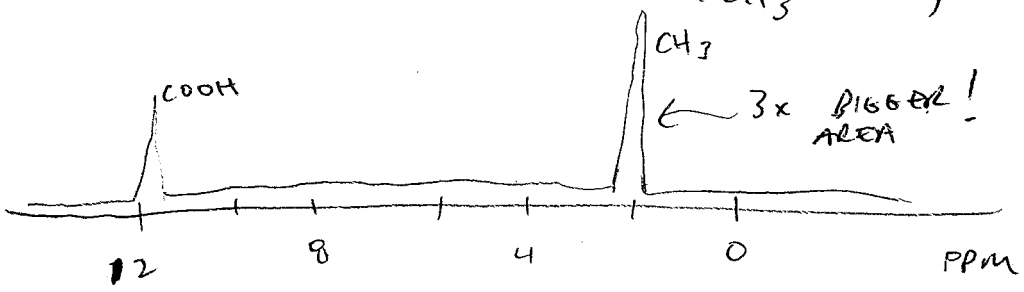
FOR ANY GIVEN NUCLEUS:

$$B_{eff} = B_0(1 - \sigma)$$

σ ↑ SHIELDING CONSTANT SPECIFIC TO CHEMICAL ENVIRONMENT OF NUCLEUS.

- BY CONVENTION IN NMR, THE FREQUENCY AXIS IS REVERSED.
- WE OFTEN GIVE SHIFTS IN PARTS PER MILLION (PPM)

NMR SPECTRUM OF ACETIC ACID (CH_3COOH)



- IN HUMANS, THE MOST ABUNDANT ^1H SPECIES ARE WATER (H_2O) AND FAT (LIPIDS ⇒ MANY CH_2 GROUPS)

FAT IS ≈ 3.5 ppm LOWER THAN H_2O