

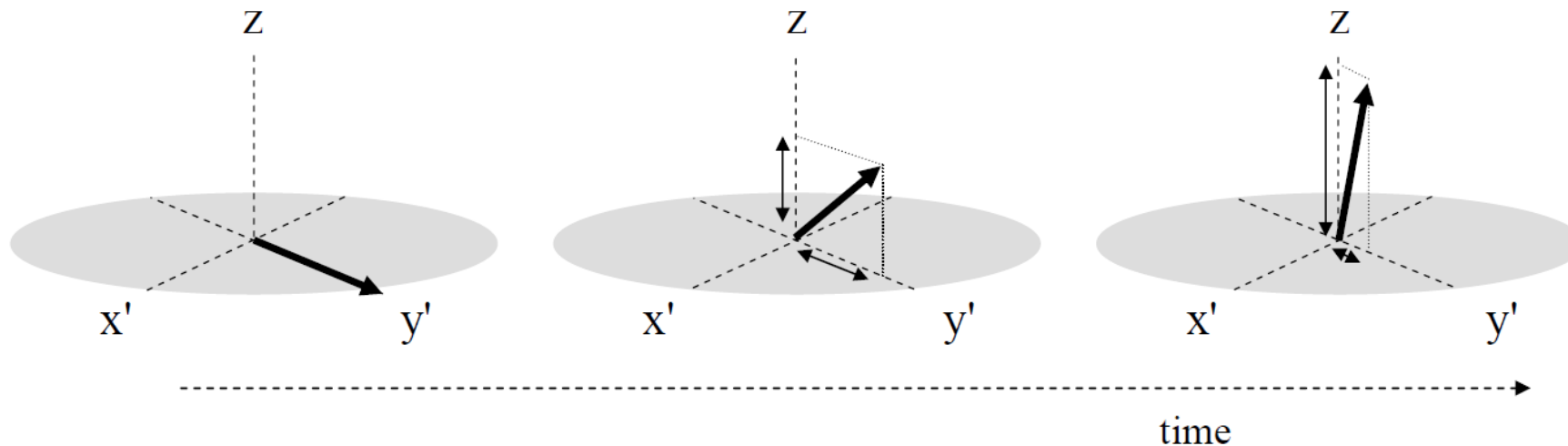
# Lecture 20 – Relaxation Time

**This lecture will cover:**

- Relaxation time (弛豫时间)
- Free induction decay

# Relaxation time

- The equilibrium magnetization state
  - The z-component,  $M_z$  equal to  $M_0$
  - The transverse components,  $M_x$  and  $M_y$ , equal to zero
- Two relaxation time (弛豫时间)
  - $T_1$ -relaxation (纵向弛豫): the z-component from  $M_z$  to  $M_0$  (spin-lattice relaxation, 自旋-晶格弛豫)
  - $T_2$ -relaxation (横向弛豫): the transverse components from  $M_x$  and  $M_y$  to 0 (spin-spin relaxation, 自旋-自旋弛豫)



**Fig.** (left) Magnetization vector after a  $90^\circ$  RF pulse about the x-axis. (centre)  $T_1$  and  $T_2$  relaxation of the magnetization a certain time after the pulse has been applied results in an increased  $M_z$  component and reduced  $M_y$  component, respectively. (right) After a further time, the  $M_z$  and  $M_y$  components have almost returned to their equilibrium values of  $M_0$  and zero, respectively.

# Relaxation time

- For an arbitrary tip angle  $\alpha$  for  $M_z$  component:

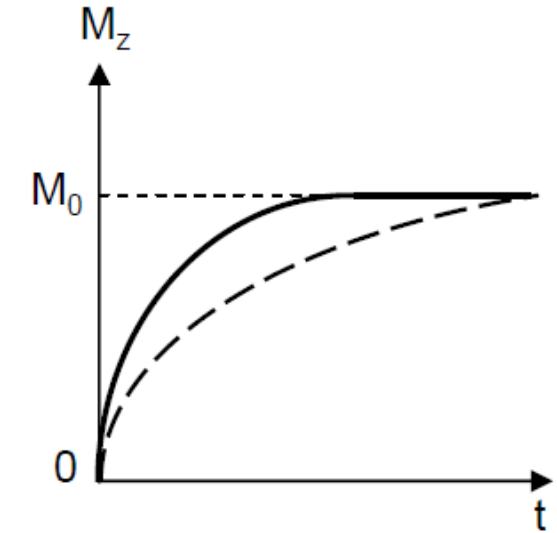
$$M_z(t) = M_0 \cos \alpha + (M_0 - M_0 \cos \alpha) (1 - e^{-\frac{t}{T_1}})$$

- For an arbitrary tip angle  $\alpha$  for  $M_{x,y}$  component:

$$M_{x,y}(t) = M_0 \sin \alpha e^{-\frac{t}{T_2}}$$

**Table** Tissue relaxation times (ms) at 1.5 and 3 Tesla

Tissue	$T_1$ (1.5 T)	$T_1$ (3 T)	$T_2$ (1.5 T)	$T_2$ (3 T)
Brain (white matter)	790	1100	90	60
Brain (grey matter)	920	1600	100	80
Liver	500	800	50	40
Skeletal muscle	870	1420	60	30
Lipid (subcutaneous)	290	360	160	130
Cartilage	1060	1240	42	37



**Fig.** The recovery of  $M_z$  magnetization as a function of time after a 90 pulse for a tissue with short  $T_1$  relaxation time (solid line) and long  $T_1$  relaxation time (dashed line). When  $t = 5 \cdot T_1$ ,  $M_z \sim 99\% M_0$ , which is assumed to be full recovery.

# $T_2$ -relaxation time

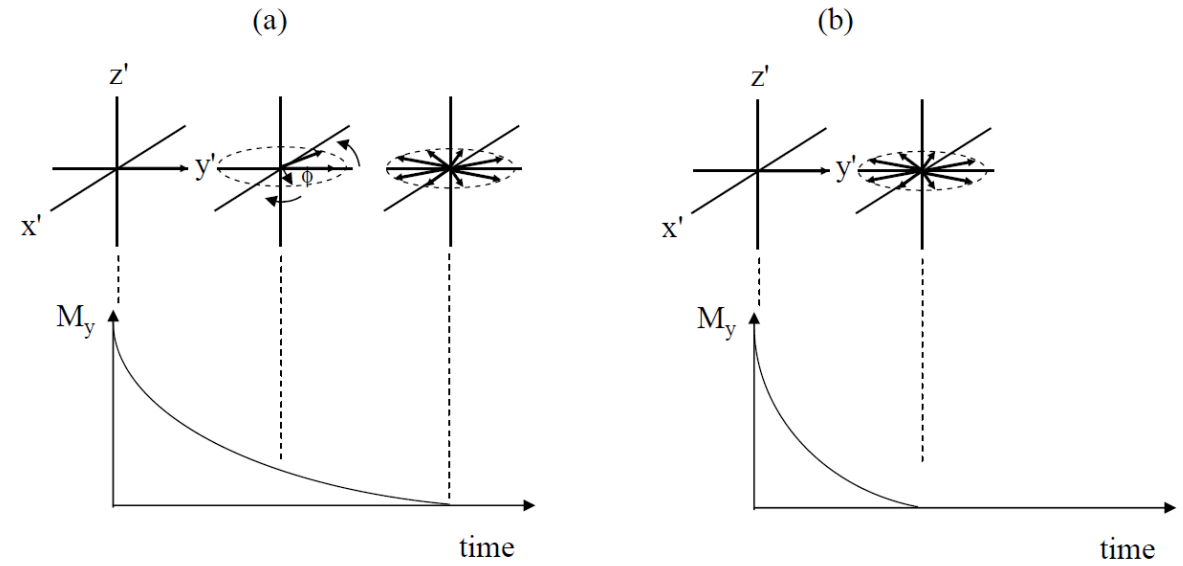
➤  $T_2$ -relaxation time is affected by the spatial inhomogeneity in the  $B_0$  field which is caused by

- Non-uniform  $B_0$  over the entire imaging volume
- Different magnetic susceptibilities (磁化率) of different parts of the body, i.e. metal implant.

➤ The combined relaxation time

$$\frac{1}{T_2^*} = \frac{1}{T_2^+} + \frac{1}{T_2}$$

Where  $T_2^+$ : a relaxation time characterized by  $B_0$  inhomogeneity



**Fig.** The time-dependence of the  $M_y$  component of magnetization for (a) a tissue with relatively long  $T_2^*$  and (b) one with a shorter  $T_2^*$ . The decrease in signal occurs due to the loss of phase coherence of the protons, i.e. protons precess at slightly different frequencies, thus acquiring different phases and reducing the net magnetization along the y-axis. The faster the dephasing process the shorter the  $T_2^*$  relaxation time.

# Chemical shift (化学位移)

- Protons resonate very close to the same frequency for water within tissue, but protons in lipid resonate at a significantly different frequency.

- The effective magnetic field:

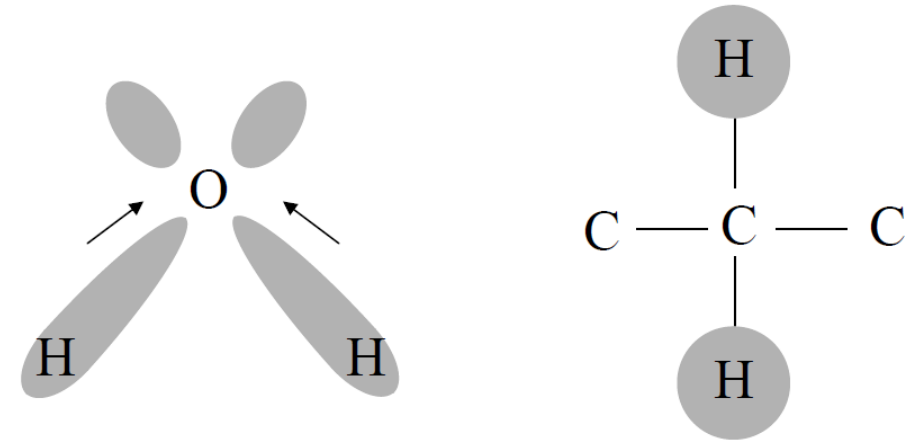
$$B_{\text{eff}} = B_0(1 - \sigma)$$

where  $\sigma$  is the shielding constant;

- The resonant frequency of the proton in lipid:

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

- Magnetic resonance spectroscopy (MRS): study metabolic changes in organs or tissues based on the resonant frequency and intensity



**Fig.** The electron density distribution (shaded area) surrounding protons in water and lipid. The strong electronegativity of the oxygen atom in water pulls electrons away from the proton, leaving it unshielded compared to the protons in lipid.

# Tissue relaxation time

- Free water (自由/游离水) and bound water (束缚/结合水)
  - Free water (~90%): longer  $T_1$  and  $T_2$
  - bound water (~10%): bound with large molecules, shorter  $T_1$  and  $T_2$
- Factors affecting relaxation time
  - Water content (free water)
  - The movement of water molecules
  - The movement of large molecules
  - Lipid content
  - Paramagnetic particles (顺磁粒子)

# Lecture 20 – Relaxation Time

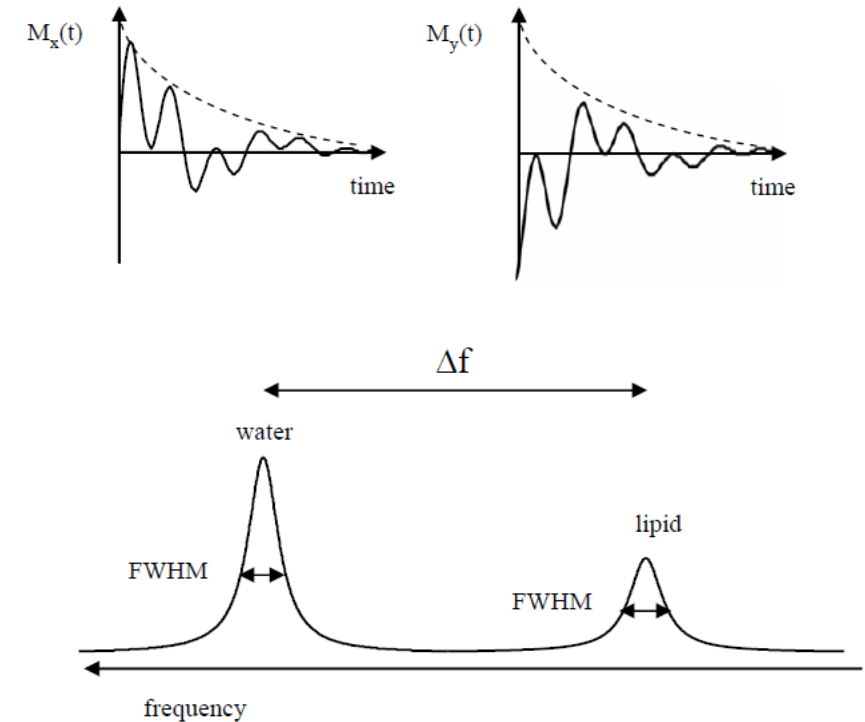
This lecture will cover:

- Relaxation time (弛豫时间)
- **Free induction decay**

# Free induction decay

## The free induction decay (FID, 自由感应衰减)

- The measured MR signal from tissues;
- Caused by the change of magnetization during the relaxation;
- The signal processed freely after the RF pulse has been turned off;
- Decay to a zero equilibrium value;
- Both  $M_x$  and  $M_y$  components can be detected;
- Electronic signal produced by EM induction with frequency of  $\omega_0$  and time constant  $T_2^*$ ;
- Most convenient to observe in the frequency domain
- The linewidth of each peak give by  $1/\pi T_2^*$



**Fig.** (top) x- and y-components of magnetization as a function of time, showing 'beat patterns' which come from the two different resonant frequencies of lipid and water. The real part of the frequency spectrum, shown on the bottom, shows the two peaks separated by  $\Delta f$  Hz.



# FID signal

## Characteristics of FID signals

- Only  $M_x$  and  $M_y$  can be measured,  $M_z$  can be measured if it is rotated to x-y plane;
- Initial amplitude of FID is proportional to the density of protons in tissues;
- Under the circumstance of same density of protons, the longer  $T_2$ , the slower decay, the greater FID signal;
- Under the circumstance of same measurement time, the shorter  $T_1$ , the greater FID signal;
- The intensity of FID signals are affected by density of protons,  $T_1$  and  $T_2$ , therefore MRI is multiple-parameter imaging.