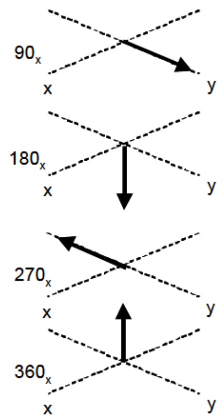
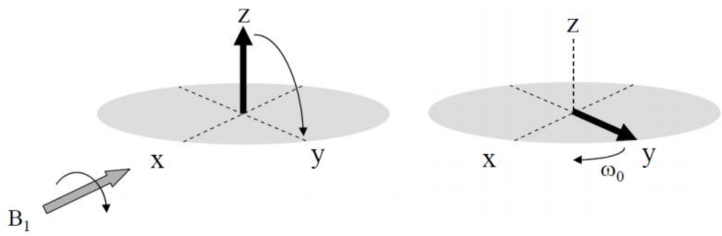
Homework 5 Solution

1. Show schematically the separate effects of: (i) a 90x°, (ii) a 180x°, (iii) a 270x°, and (iv) a 360x° pulse on thermal equilibrium magnetization using the vector model. (10')

Solution.

The net effect is to produce rotation of the magnetization about the x-axis towards the y-axis.





2. Answer true or false with 1-2 sentences of explanation:

(a) recovery of magnetization along the z-axis after a 90° pulse does not necessarily result in loss of magnetization from the xy-plane.

(b) a static magnetic field B_0 that is homogeneous results in a free induction decay which persists for a long time.

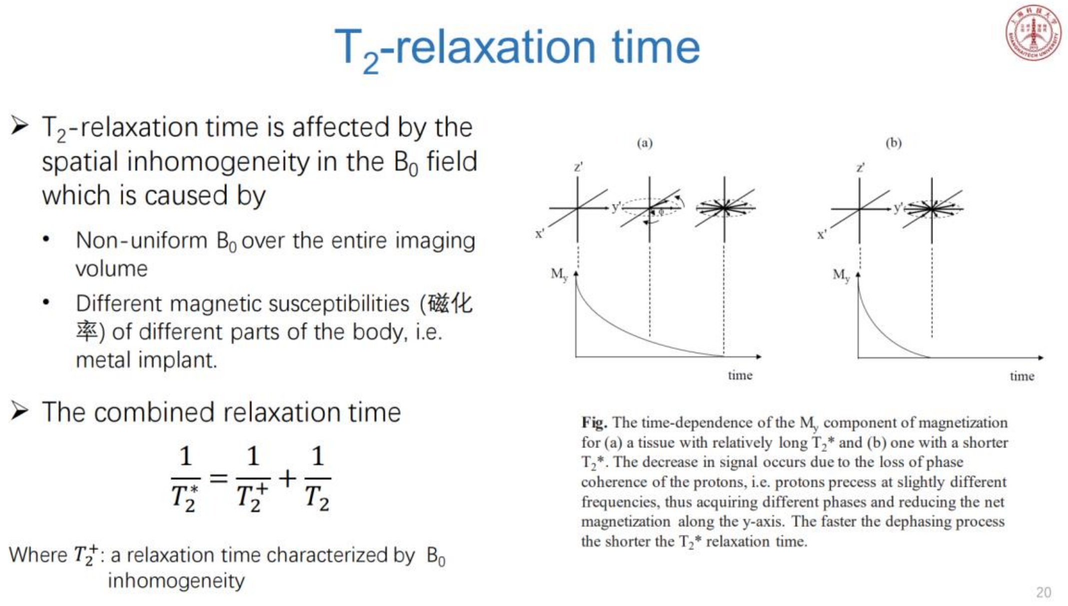
(c) a short tissue T1 indicates a slow spin-lattice relaxation process.

(10’)

Solution.

(a) False. The total magnetization, given by √(Mx2+My2+Mz2) must be less or equal to M_0. After a 90° pulse, the value of Mz is zero, but this increases as a function of time due to T1 relaxation. Therefore, the transverse magnetization must decrease as a function of time.

(b) True. If the B_0 field is inhomogeneous, nuclei at different positions will process at different rates and hence the spin system dephases faster, which results in a shorter free induction decay. So the more homogeneous the B_0 field the longer the FID lasts.



(c) False. A shorter T1 means that it takes shorter time for the spin system resumes to its thermal equilibrium state, which corresponds to faster relaxation.

3. The operator wishes to acquire an oblique slice shown by the orientation of the white bar in Figure 1. Draw the gradient echo imaging sequence that would be run to acquire such an image. (20’)

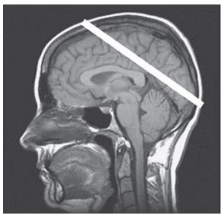
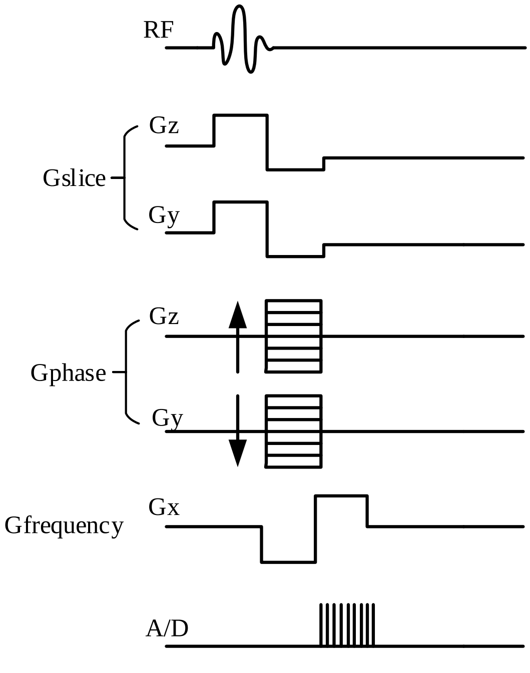
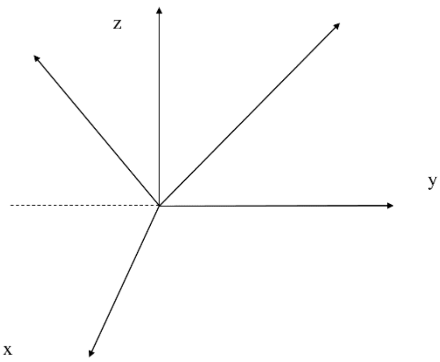


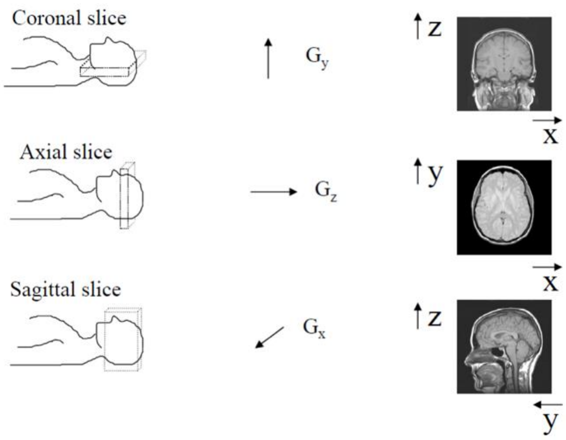
Figure 1

Solution.

The oblique slice is in the head/foot (z) and anterior/posterior (y) planes, and therefore both gradients must be applied in the slice select direction, with approximately equal strengths since the slice is at an angle of ~45°. Since the phase and frequency encoding gradients are both applied <u>orthogonal</u> to the slice selection gradient, both phase and frequency encoding must also have contributions from two gradients. So the sequence is (note that the phase and frequency axes can be interchanged).







4. In the image shown in Figure 2, acquired using a standard spin-echo sequence, the bright signal corresponds to lipid and the lower intensity signal to water. The lipid and water signals appear spatially shifted with respect to one another. (20')

(a) Given the facts above, which of the left/right or up/down dimensions corresponds to the frequency encoding direction, and which to the phase encoding direction? Explain your answer fully.

(b) The image is acquired at a field strength of 3 Tesla, and the black band in the image is 3 pixels wide. If the total image data size is 256 × 256, what is the overall data acquisition bandwidth? The image field-of-view is 5×5 cm: what is the strength of the frequency encoding gradient?

(c) If the frequency encoding gradient were increased by a factor of 3, what effect would this have on the imaging artifact?

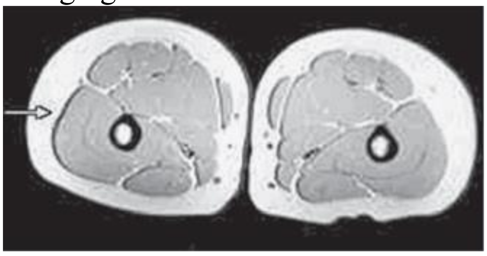
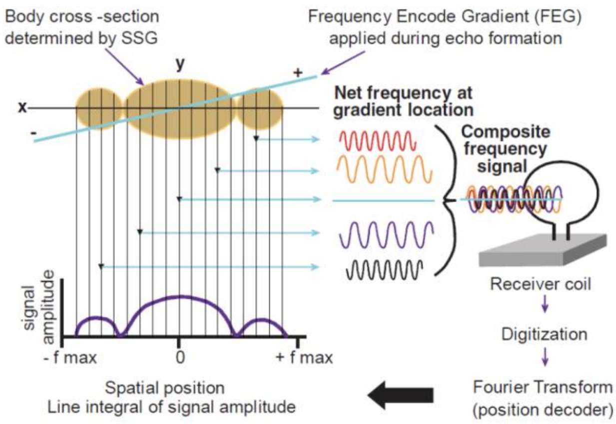


Figure 2

Solution.

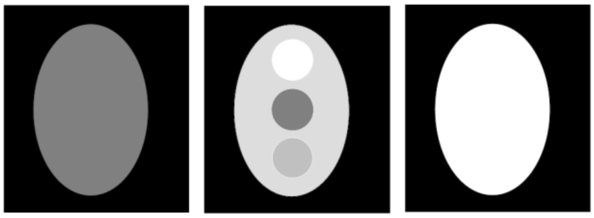


(a) We know that fat and water resonate at different frequencies, with a difference of approximately 3 ppm, corresponding to ~390 Hz (or ~400Hz) at 3 Tesla. Since spatial dimensions are represented by different resonant frequencies in the presence of a frequency-encoding gradient, the images from fat and water will be displaced slightly. This causes signal "pile-up" on one side and a signal void (shown as a black line) on the other. So the left/right direction is the frequency encoding and up/down the phase encoding direction in the image.

(b) Since the black band is 3 pixels wide and corresponds to a shift of 390 Hz, the full image width of 256 pixels corresponds to a data acqusition bandwidth of 256*(390/3)= 33.28 kHz. Since the field-of-view is 5 cm, the gradient strength is 33280/5=6656 Hz/cm.

(c) Increasing the frequency encoding gradient by a factor of three to ~20 kHz/cm would increase the bandwidth to ~100 kHz. The frequency shift between fat and water is unchanged at 390 Hz, but this now corresponds to a shift of only one, rather than three, pixels. Therefore, the image artifact would become less severe.

5. Three MRIs of the brain are acquired using identical parameters except for the TR and TE times. Three tumours (upper, middle and lower) are seen in one of the images but not in the other two, as shown in Figure 4. If the T_1 values for all the tissues (tumours and brain) are less than 2 seconds, and the T_2 values are all greater than 80 ms, describe the *relative* values of proton density, T_1 and T_2 of brain tissue and the three tumours. (20')



TR=0.5 s, TE=80 ms TR=0.5 s, TE=1 ms TR=10 s, TE=1 ms

Figure 4

Solution.

Imaging parameters	Image weighting
$TE \ll T_2^*$, and either $\alpha \ll \alpha_{Ernst}$ or $TR \gg T_1$ or both	proton density
$TE \ll T_2^*$, and either $\alpha \sim \alpha_{Ernst}$ or $TR \sim T_1$ or both	T_1-weighted
$TE > T_2^*$, and either $\alpha \ll \alpha_{Ernst}$ or $TR \gg T_1$ or both	T_2^*-weighted
$TE > T_2^*$, and either $\alpha \sim \alpha_{Ernst}$ or $TR \sim T_1$ or both	mixed T_1- and T_2^*-weighted

The image 3 is proton-density weighted due to the long TR and short TE. This shows that the proton density of the three tumours and the brain tissue are the same.

The image 2 is T_1 weighted due to the short TR and short TE. Therefore the T_1 value: upper < brain < down < middle.

The image 1 is mixed T_1 and T_2 weighted.

$$I = k\rho(1-e^{-TR/T_1})e^{-TE/T_2}$$

$T_1\uparrow$, $e^{-TR/T_1}\uparrow$ $(1-e^{-TR/T_1})\downarrow$

$\therefore e^{-TE/T_2}\uparrow$

$\therefore T_2\uparrow$

T_2 value: upper < brain < down < middle.

6. Design an EPI pulse sequence that gives the square spiral k-space trajectory shown in Figure 3. (20')

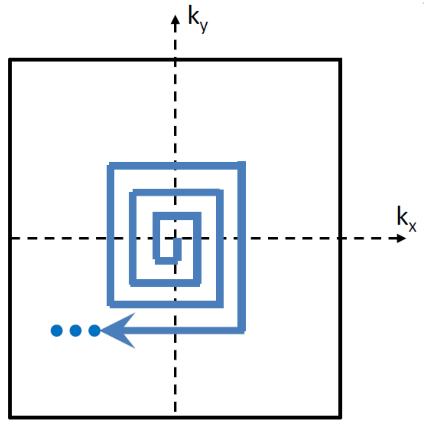


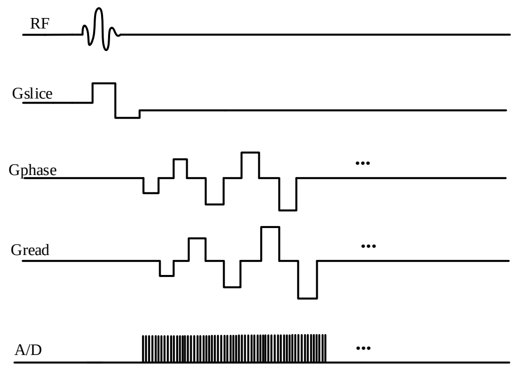
Figure 3

Solution.

In addition to the direction, two characteristics must be shown in your figure:

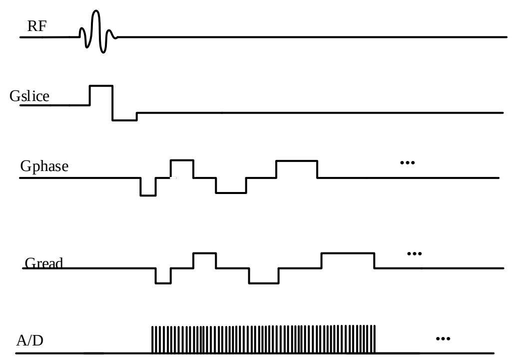
1.

- The amplitude is gradually increasing.
- A/D is always on.

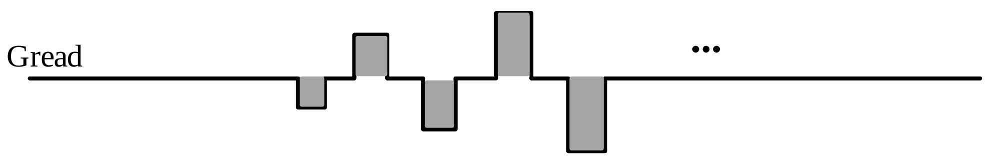


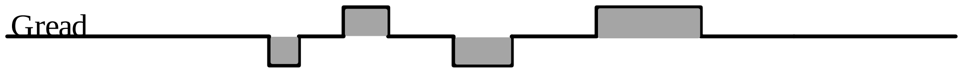
Or 2.

- Each pulse time is gradually increasing.
- A/D is always on.

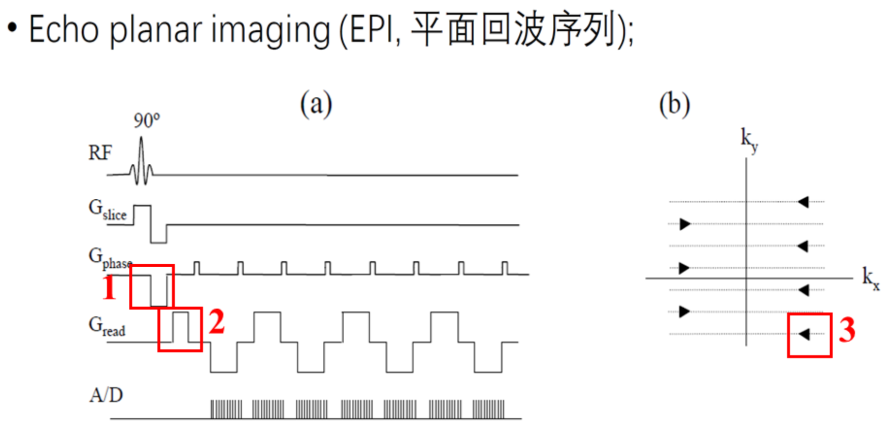


In fact, in 1 and 2, the increasing characteristic is the area of shadows,





About the initial position:
In Slides 19th, page 14,
The sequence of marker 1 and 2 denote the initial position of marker 3, which is at the maximum negative values of k_y and maximum positive values of k_x.



In this problem, the initial position of k-space is in origin, so the sequence of marker 1 and marker 2 are just two lines (may be two points). That means we don't need to draw it.