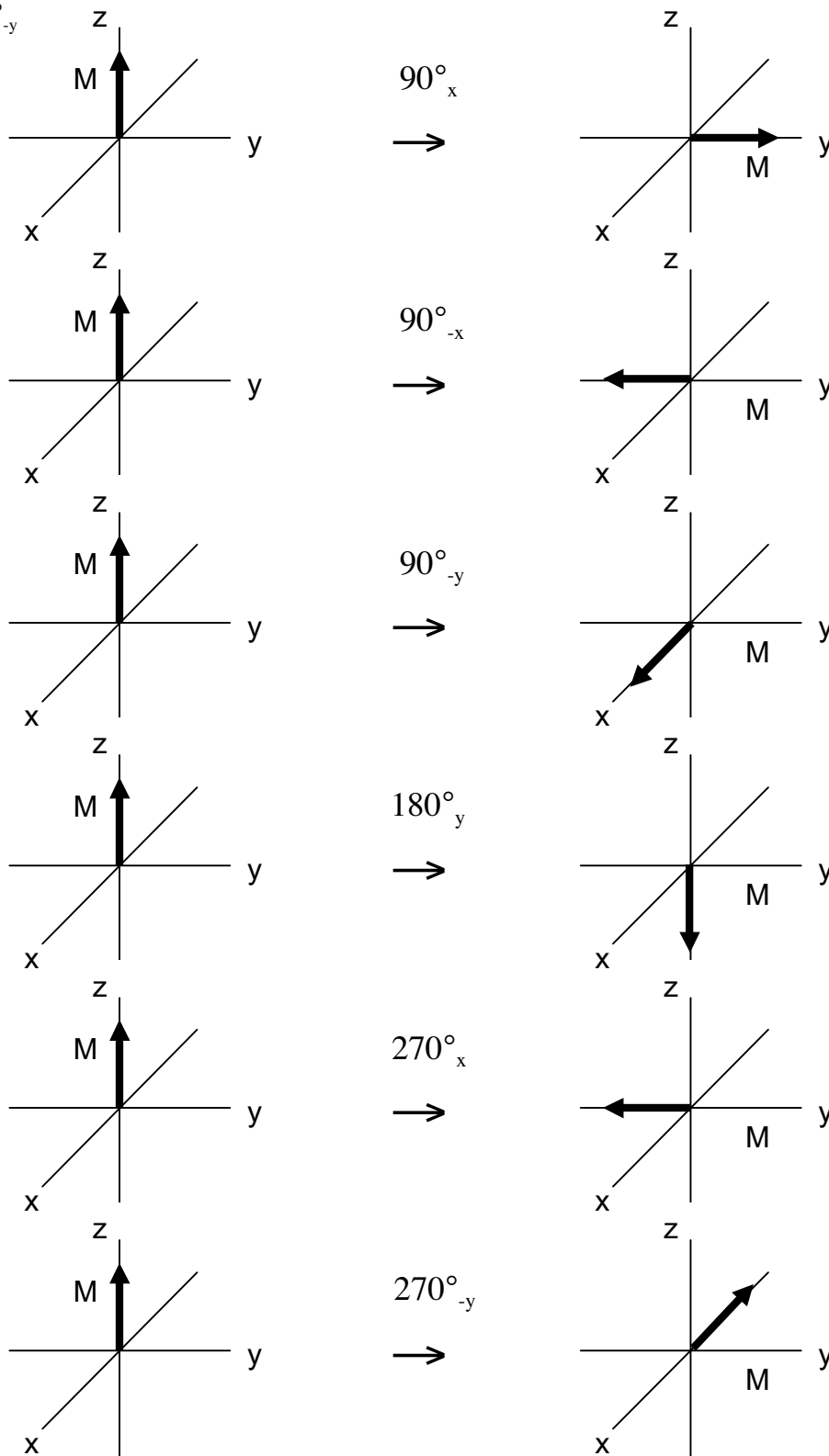
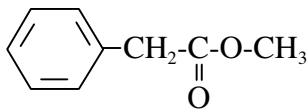


Problem Set #2, CHEM/BCMB 4190/6190/8189

1). The effect on the bulk magnetization vector, M , of a 90° ($\pi/2$) pulse applied along the “x” axis (90°_x) is shown below. Show what effect the following pulses would have: 90°_{-x} , 90°_{-y} , 180°_y , 270°_x , 270°_{-y}



2). Using Shooley's rule for methylene groups, predict the ^1H chemical shift for the (equivalent) methylene protons of the following compound:



The ^1H chemical shifts of methylene protons in disubstituted compounds of the form $\text{X}-\text{CH}_2-\text{Y}$ can be estimated using *Shooley's rule*:

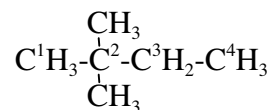
$$\delta(\text{CH}_2) \text{ } ^1\text{H} \text{ (ppm)} = 0.23 + S_x + S_y$$

where S_x and S_y are values derived empirically for specific substituents X and Y (see table).

For this compound, $S_x = 1.83$ and $S_y = 1.55$, so $\delta(^1\text{H}) = 0.23 + 1.83 + 1.55 = 3.61$ ppm (actual, 3.60).

Substituent	S	Substituent	S
$-\text{CH}_3$	0.47	$-\text{NRR}'$	1.57
$-\text{CF}_3$	1.14	$-\text{SR}$	1.64
$-\text{CR}=\text{CR}'\text{R}''$	1.32	$-\text{I}$	1.82
$-\text{COOR}$	1.55	$-\text{OH}$	2.56
$-\text{CONH}_2$	1.59	$-\text{OCOR}$	3.13
$-\text{C}_6\text{H}_5$	1.83	$-\text{OC}_6\text{H}_5$	3.23

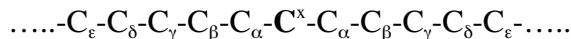
3). Using the Grant and Paul incremental system for alkanes, predict the ^{13}C chemical shifts for all of the non-equivalent ^{13}C nuclei in 2,2-dimethylbutane (the actual shifts are; $\delta^{13}\text{C}^1=29.1$, $\delta^{13}\text{C}^2=30.6$, $\delta^{13}\text{C}^3=36.9$, and $\delta^{13}\text{C}^4=8.9$ ppm):



According to the Grant and Paul system for calculating $\delta^{13}\text{C}$ for alkanes:

$$\delta^{13}\text{C} \text{ (ppm)} = -2.3 + 9.1n_\alpha + 9.4n_\beta - 2.5n_\gamma + 0.3n_\delta + 0.1n_\epsilon + \Sigma(\text{steric corrections})$$

where n_α , n_β , etc. are the numbers of α , β , etc. carbons defined relative to the carbon nucleus of interest (C^x) as shown below:



whereas the steric corrections are shown in the following table:

steric corrections (ppm)				
carbon nucleus of interest	type of carbons attached			
	primary	secondary	tertiary	quaternary
primary	0	0	-1.1	-3.4
secondary	0	0	-2.5	-7.5
tertiary	0	-3.7	-9.5	-15.0
quaternary	-1.5	-8.4	-15.0	-25.0

For 2,2-dimethylbutane;

C^1 : $n_\alpha=1$, $n_\beta=3$, $n_\gamma=1$, $n_\delta=n_\epsilon=0$, and for the steric corrections, one quaternary carbon (C^2) attached to the primary $\text{C}^1 = 1(-3.4)$

$$\delta^{13}\text{C}^1 = -2.3 + 9.1(1) + 9.4(3) - 2.5(1) + 0.3(0) + 0.1(0) + 1(-3.4) = 29.1 \text{ ppm}$$

C^2 : $n_\alpha=4$, $n_\beta=1$, $n_\gamma=n_\delta=n_\epsilon=0$, and for the steric corrections, three primary carbons (C^1 and adjacent methyl groups) and one secondary carbon (C^3) attached to one quaternary carbon (C^2) = $3(-1.5)+1(-8.4)$

$$\delta^{13}C^1 = -2.3+9.1(4)+9.4(1)-2.5(0)+0.3(0)+0.1(0)+3(-1.5)+1(-8.4) = 30.6 \text{ ppm}$$

C^3 : $n_\alpha=2$, $n_\beta=3$, $n_\gamma=n_\delta=n_\epsilon=0$, and for the steric corrections, one quaternary carbon (C^2) and one primary carbon (C^4) attached to the secondary C^3 = $1(-7.5)+1(0)$

$$\delta^{13}C^1 = -2.3+9.1(2)+9.4(3)-2.5(0)+0.3(0)+0.1(0)+1(-7.5) = 36.6 \text{ ppm}$$

C^4 : $n_\alpha=1$, $n_\beta=1$, $n_\gamma=3$, $n_\delta=n_\epsilon=0$, and for the steric corrections, one secondary carbon (C^3) attached to the primary C^4 = $1(0)$

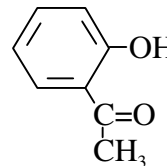
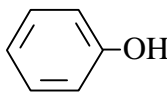
$$\delta^{13}C^1 = -2.3+9.1(1)+9.4(1)-2.5(3)+0.3(0)+0.1(0)+1(0) = 8.7 \text{ ppm}$$

4). In a 1% solution, the chemical shift of the hydroxyl 1H of phenol is approximately 4.37 ppm. The chemical shift increases with concentration up to 7.45 ppm at 100%. Conversely, the chemical shift of the hydroxyl 1H of *o*-hydroxyacetophenone is very high (12.05 ppm), and is invariant with concentration.

a. Why does the chemical shift of the 1H of the hydroxyl of phenol change with concentration, and why does the chemical shift increase when the concentration increases?

b. Why is the chemical shift of the 1H of the hydroxyl of *o*-hydroxyacetophenone so high?

c. Why does the chemical shift of the 1H of the hydroxyl of *o*-hydroxyacetophenone not change with concentration?



a. The change with concentration is due to intermolecular interactions between phenol molecules. Increasing concentration increases the likelihood of the intermolecular interactions, and thus the effect becomes more apparent as the concentration increases. The specific interaction is hydrogen bonding (*intermolecular*), as the hydroxyl group can act as both a hydrogen bond donor and hydrogen bond acceptor. A hydrogen bonded hydroxyl 1H nucleus will be deshielded relative to one that is not hydrogen bonded, thus the chemical shift increase.

b. The chemical shift of the hydroxyl 1H of *o*-hydroxyacetophenone is 12.05 ppm! This must be due to the fact that it is hydrogen bonded. Furthermore, based on the result for phenol, we might guess that this is an *intramolecular* hydrogen bond, as the chemical shift for the intermolecular hydrogen bond is only 7.45 (compared to 12.05), and one might infer that proper molecular geometry *could* produce a very strong *intramolecular* hydrogen bond with high deshielding.

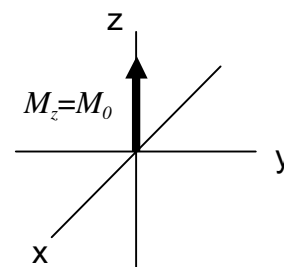
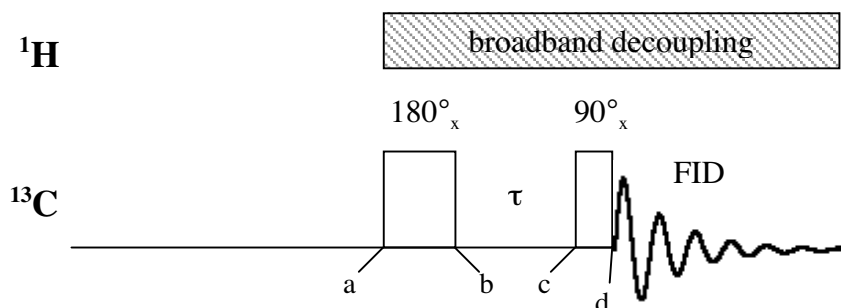
c. The fact that the chemical shift is invariant with concentration suggests strongly that the hydrogen bond is in fact *intramolecular* and not *intermolecular*. A dependence on concentration, as in the case of phenol, of the chemical shift would be expected for an intermolecular hydrogen bond.

5). If the longitudinal relaxation time for a given nucleus is 10 seconds, how long after a 180° pulse will we have to wait until the magnitude of the z component of the bulk magnetization (M_z) is equal to 95% of the magnitude of the bulk magnetization before the pulse (M_0)?

We assume, as did Bloch, that this relaxation process is first order, and $M_z = M_0(1 - 2e^{-t/T_1})$.

$$M_z / M_0 = 0.95 = (1 - 2e^{-t/T_1}) = (1 - 2e^{-t/10s}) \quad 2e^{-t/10s} = 0.05 \quad e^{-t/10s} = 0.025 \quad -t/10s = -3.68888 \quad t \approx 37s$$

6). The following diagram represents the pulse sequence (experiment) used to measure T_1 for ^{13}C nuclei:



a. At point 'a', just before the first (180°_x) pulse, the magnitude of the longitudinal component of the bulk ^{13}C magnetization (M_z) is equal to the magnitude of the equilibrium magnetization (M_0), as shown in the vector diagram at the right. Draw similar diagrams for points 'b', 'c', and 'd' showing the effects of the pulses and delays, assuming $\tau=0.0$ seconds.

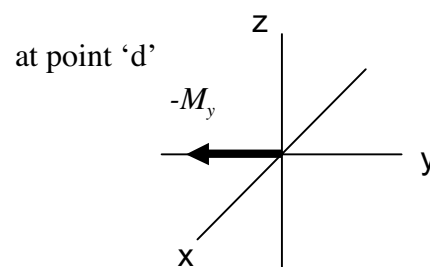
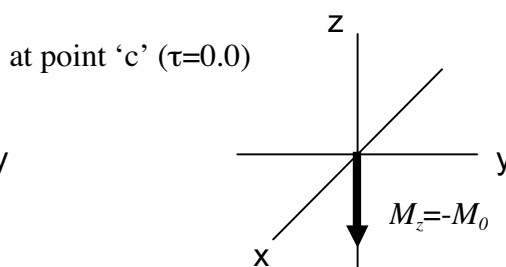
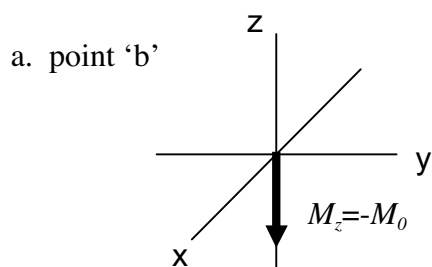
b. After point 'd', if we record the FID (for $\tau=0.0$ s) and perform a Fourier transform on it, what will the resulting signal look like (sketch the signal)?

c. Draw sketches of the vector diagrams at points 'c' and 'd' and the Fourier transforms of the FIDs collected after point 'd' for increasing values of τ .

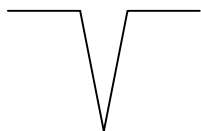
d. At some value of τ (see question 'c'), the magnitude of the longitudinal component of the bulk magnetization is zero ($M_z=0$) at point 'c', and the Fourier transform of the FID reveals no signal. If T_1 is 10 seconds, at what value of τ does this occur?

e. You find that when τ is 10s, there is no signal at point 'd'. What is T_1 ?

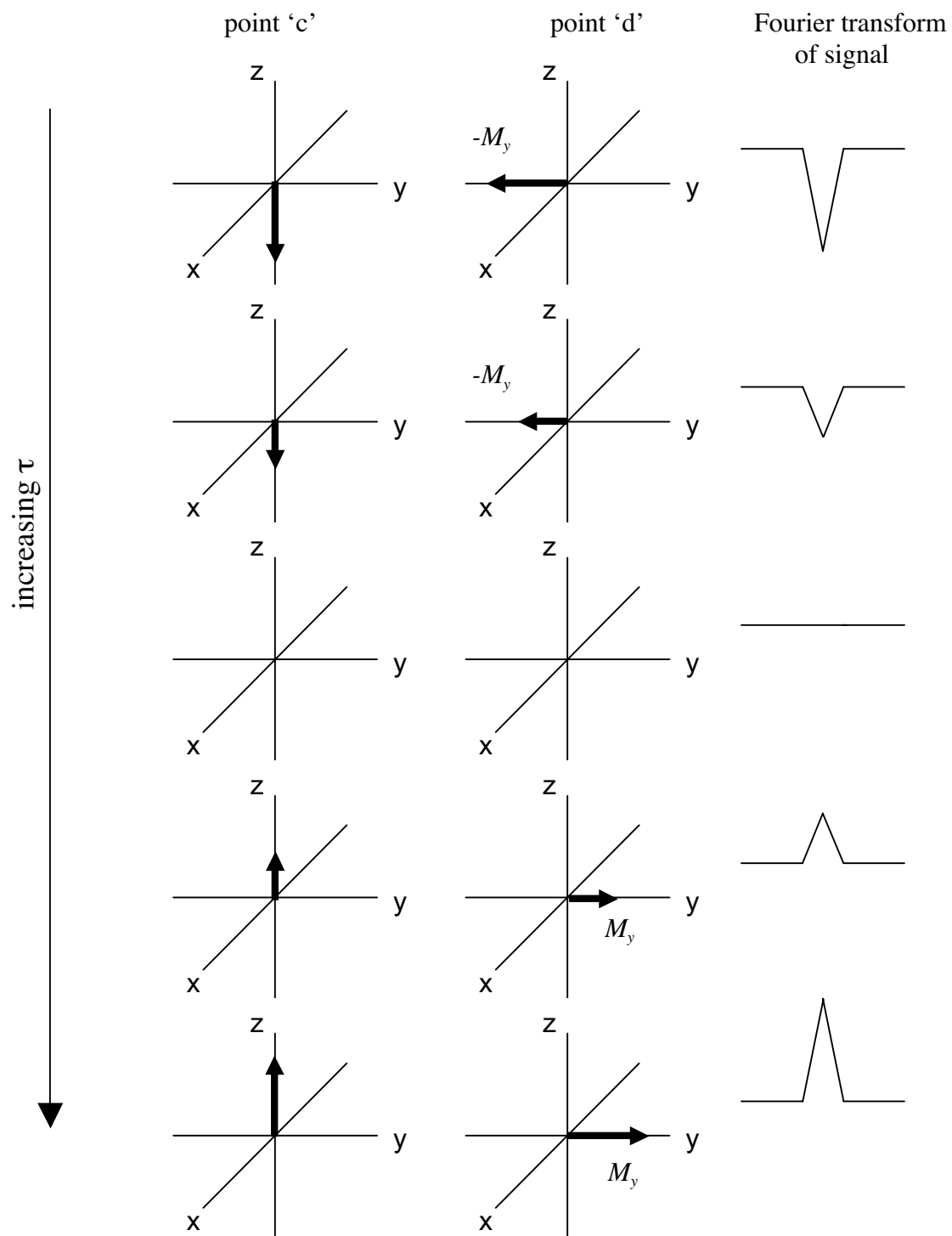
f. In order to measure T_1 properly, we measure the amplitude of the signal (Fourier transform of the FID) as a function of τ and fit the data to the appropriate first order equation. We should wait for a time equal to at least $5T_1$ between successive experiments in order to allow for re-equilibration of the bulk magnetization. If T_1 is 10 s, and if we wait for $5T_1$ between experiments, how complete is the re-equilibration (assume $\tau=0$, the acquisition time=0 and the 90° pulse width is also=0)?



b.



c.



d. Again, we assume, as did Bloch, that this relaxation process is first order, and $M_z = M_0(1 - 2e^{-t/T_1})$. When $M_z=0$;

$$0 = M_0(1 - 2e^{-\tau/T_1}) \quad 0 = M_0 - 2M_0e^{-\tau/T_1} \quad M_0 = 2M_0e^{-\tau/T_1} \quad 1 = 2e^{-\tau/T_1} \quad \ln(1/2) = -\tau/T_1 \quad T_1 \ln(2) = \tau$$

If $T_1 = 10\text{s}$, $T_1 \ln(2) = 6.93\text{s}$. So, when $\tau = 6.93\text{s}$, no signal is observed.

e. From question 'd', we know that no signal is observed when $T_1 \ln(2) = \tau$. If $\tau = 10\text{ s}$, then $T_1 = 10\text{ s}/0.693 = 14.43\text{ s}$.

f. For $\tau=0$, from question 'a' we know that at point 'd' the vector diagram to the right describes the bulk magnetization. In this case, the equation that governs the return to equilibrium is $M_z = M_0(1 - e^{-t/T_1})$. For $t=5T_1=50\text{ s}$,

$$\frac{M_z}{M_0} = 1 - e^{-50/10} = 1 - 0.006737947 = 0.9933.$$

So, after $5T_1$, the equilibration process is $> 99\%$ complete.

