

CHEM / BCMB 4190/6190/8189

Introductory NMR

Lecture 7

Double Resonance Experiments:

- simplify spectra

Homonuclear Decoupling- ^1H NMR

Heteronuclear Decoupling- ^{13}C NMR

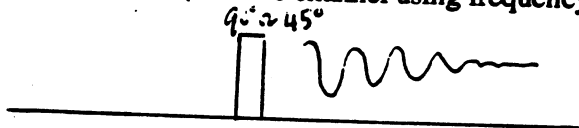
1. Homonuclear Decoupling:

We only see coupling if spins stay oriented:

$$\tau_1 = 1/J$$

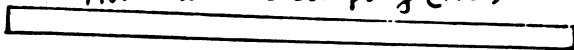
Decoupling: you shorten τ_1 by applying a second frequency ν_2 adjusted to the exact frequency of the residues to be decoupled.

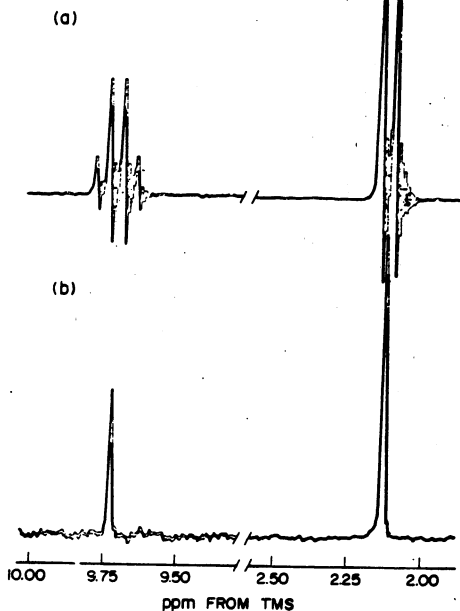
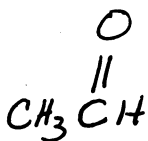
^1H transmitter (observe channel using frequency offset O1)



^1H decoupler (decoupling channel using frequency offset O2)

Homonuclear Decoupling (HD)





The normal (a) and double resonance (b) spectra of acetaldehyde, observed as a 25% (vol./vol.) solution in CCl_4 at 60 MHz.

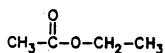
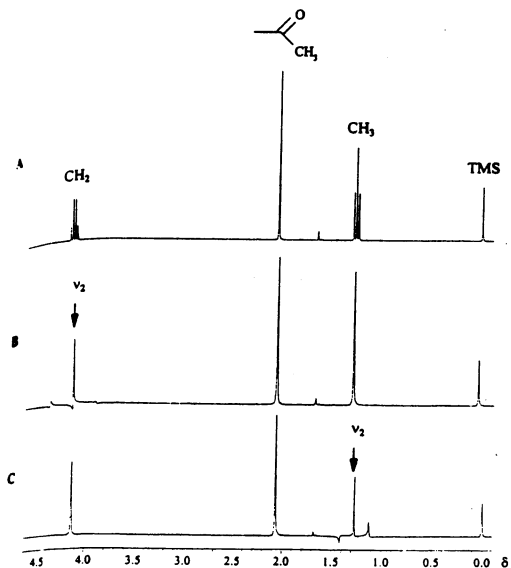
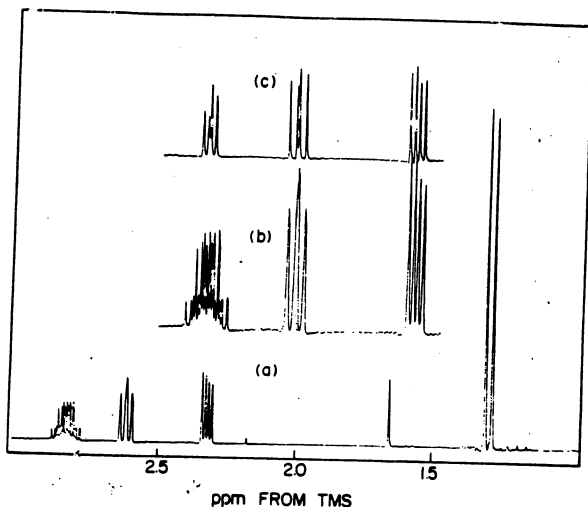
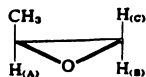


Figure 5-1.
 A: 300 MHz ^1H NMR spectra of ethyl acetate (1).
 B: CH_2 protons decoupled.
 C: CH_3 protons decoupled.



The double resonance proton spectrum of propylene oxide, observed at 200 MHz in 1% solution in CDCl_3 at 25°C . The doublet at 1.26 ppm corresponds to the methyl group. Protons A, B, and C appear in order of increasing shielding. (The peak at *ca.* 1.7 ppm is an impurity.) Spectrum (b) is an expansion of (a). In spectrum (c) the methyl protons are irradiated, reducing the multiplet of proton A to a quartet. See text. (P. A. Mirau, unpublished observations.)

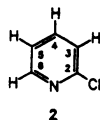
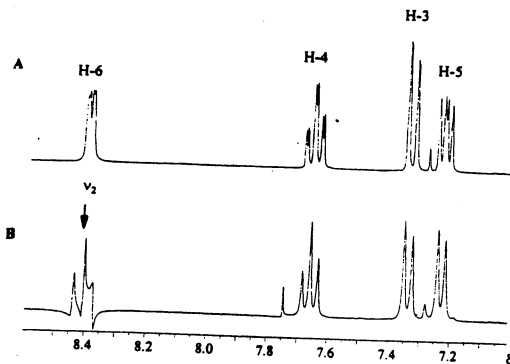


Figure 5-2.

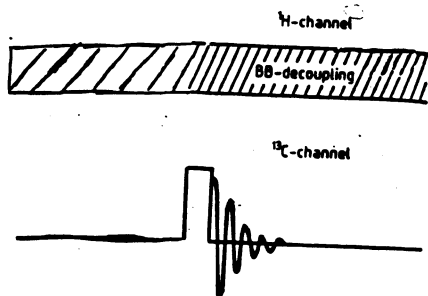
A: 300 MHz ^1H NMR spectrum of 2-chloropyridine (2).
B: H-6 decoupled.

2. Heteronuclear Decoupling:

- in ^{13}C NMR you get many signals due to ^1J coupling with hydrogen nucleus.
- makes weak signals weaker.

a) ^1H -Broad-band Decoupling:

- remove all the proton coupling.



Problems: worry about heating the sample from high B_2 .
- must cover the chemical shift range of all protons.

Solution:

- use composite pulses and complex pulse sequence (MLEV, WALTZ-16)
- Rotate the components of ^1H - ^{13}C doublets through large precession angles repetitively.

MLEV: $90^\circ (+x)$, $90^\circ (+x)$, $90^\circ (-x)$, $90^\circ (-x)$ repeated 16 times

WALTZ16: combination of 90° , 180° , and $270^\circ (\pm x)$, $(\pm y)$ using 36 pulses.

Disadvantage: lose coupling information

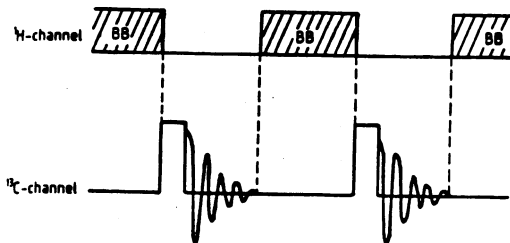
Advantage :

- 1) total intensity is concentrated into one line
- 2) signal is increased over 200 % by nuclear Overhauser effect (NOE).
 - proportional to number of protons attached
 - dependent on relaxation properties of molecule.

Net: considerably shorter recording times.

b) Gated decoupling experiment

- in Broad-band decoupling you shorten experiment time but lose coupling information.
- in gated decoupling you maintain coupling but also take advantage of most of the NOE enhancement



- during BB decoupling the NOE act on system to establish population ratio and increase intensity of signal.
- once BB decoupling is removed, the indirect spin-spin coupling returns immediately while the population ratios return slowly to equilibrium.
- T_1 relaxation times control this return and they are generally longer than the time to record the data.

Result: retain coupling and most of NOE enhancement of signal.

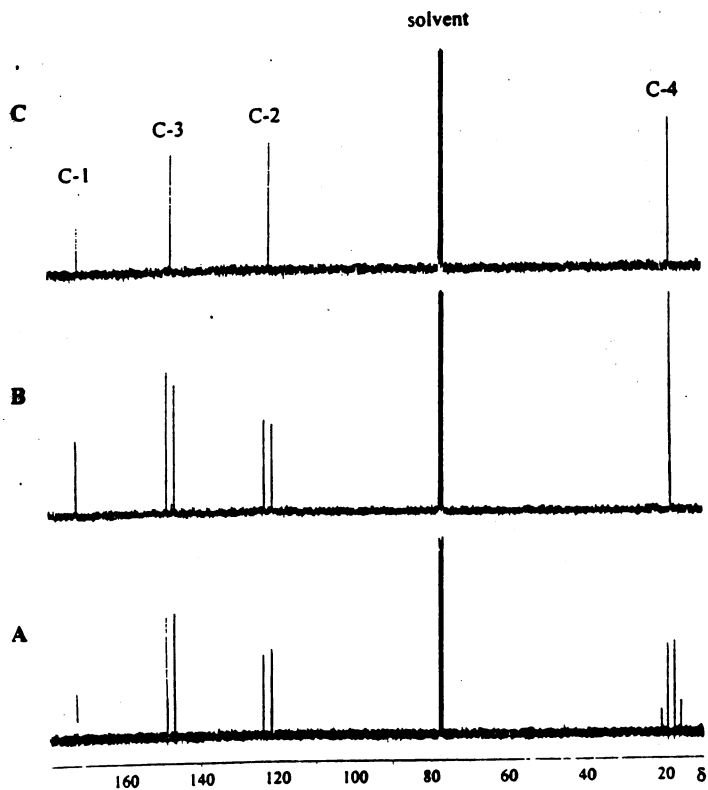
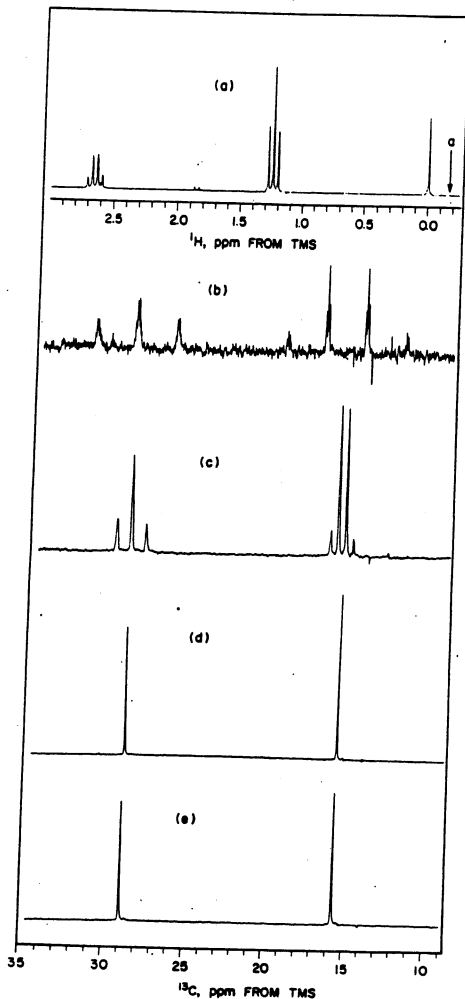


Figure 5-3.

75.47 MHz ^{13}C NMR spectra of crotonic acid (3) in CDCl_3 .

A: With ^{13}C , ^1H couplings, recorded by the gated decoupling technique.
B: With selective decoupling of the methyl protons.

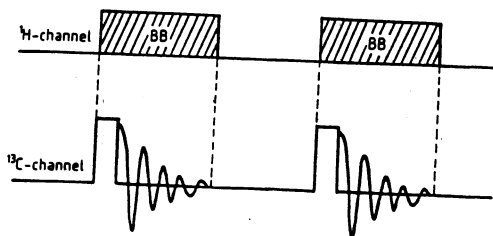
C: With ^1H broad-band (BB) decoupling.



Spectra showing various modes of $^{13}\text{C}-\{^1\text{H}\}$ decoupling. (a) 200 MHz proton spectrum of ethylbenzene, observed at 25°C using a 1% solution in CDCl_3 (1 scan); (b) 50.3 MHz ^{13}C spectrum of the same solution as in (a), without proton decoupling (60 scans); (c) off-resonance ^{13}C spectrum as in (b) but with proton decoupling at the frequency indicated by the arrow in spectrum (a) (150 scans). Spectrum (d) shows the result of employing *noise modulated* proton decoupling; in (e) an essentially identical result is obtained using MLEV decoupling (see text) but with only 1/5 of the power. Both (d) and (e) represent 60 scans. (F. C. Schilling, unpublished observations.)

Inverse Gated Decoupling- eliminated coupling and does not allow NOE enhancement.

- only apply BB-decoupling during pulse and recording.



C) ^1H Off Resonance Decoupling-

- use normal pulse technique on ^{13}C and simultaneously irradiate all of the ^1H resonances but with an intensity such that not all the C,H couplings are removed.

- usually see only one-bond couplings.

What determines the extent of decoupling?

- 1) Magnitude of the C,H coupling constant.**
- 2) interval between the resonance frequency ν_1 of the proton to be decoupled and the decoupler frequency ν_2 ($\nu_1 - \nu_2 = \Delta\nu$)**
- 3) The amplitude of B_2 at the frequency of the ^1H signal**

$$J_{\text{red}} = J \Delta\nu / \gamma B_2$$

- spectra only give qualitative information.**
- can help in assignment**
- time is longer than BB decoupling but shorter than non-decoupled.**

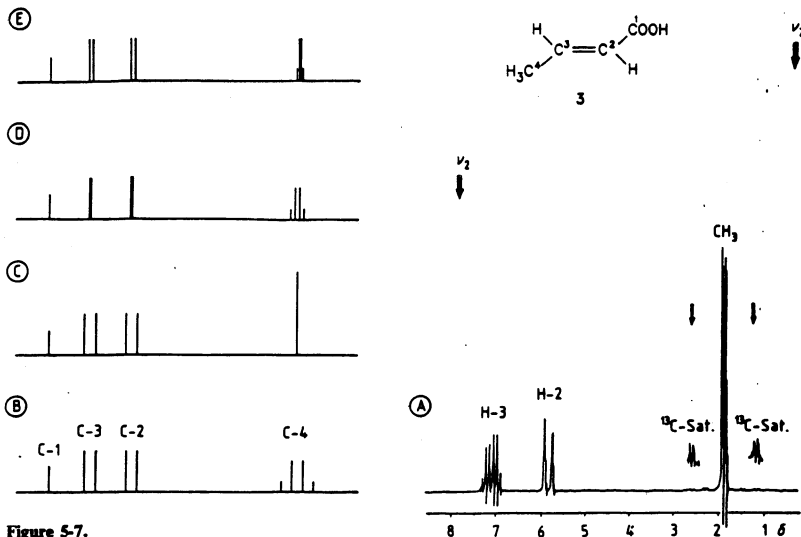


Figure 5-7.

A: 90 MHz ^1H NMR spectrum of crotonic acid (3).

B to E: ^{13}C NMR stick spectra of 3; B: without C,H decoupling;

C: selective ^1H decoupling of the methyl protons;

D: ^1H off-resonance decoupling, with decoupling frequency ν_2 at the left-hand end of the proton spectrum (at $\delta \approx 8$, shown by a thick arrow above spectrum A);

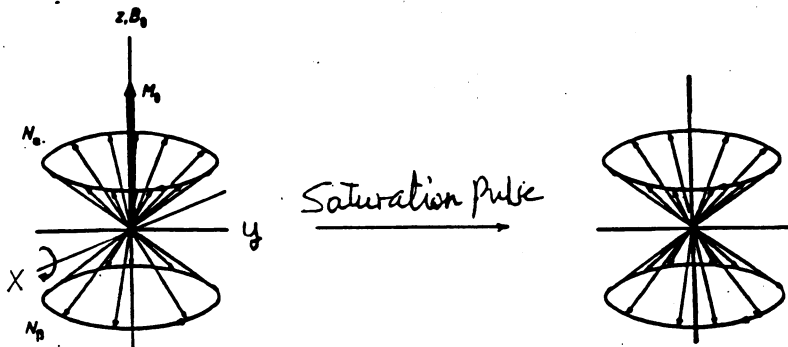
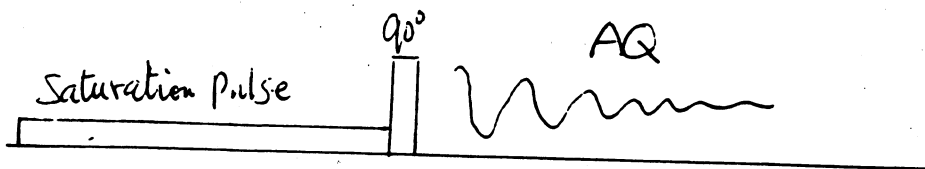
E: as in D, but with decoupling frequency ν_2 at right-hand end of proton spectrum (at $\delta \approx 1$).

d) Selective heteronuclear decoupling

- used for assignment purposes.
- signals are often separated by 125 Hz so must have sufficient decoupling power.
- works well when signals are well separated.
- not that routine.

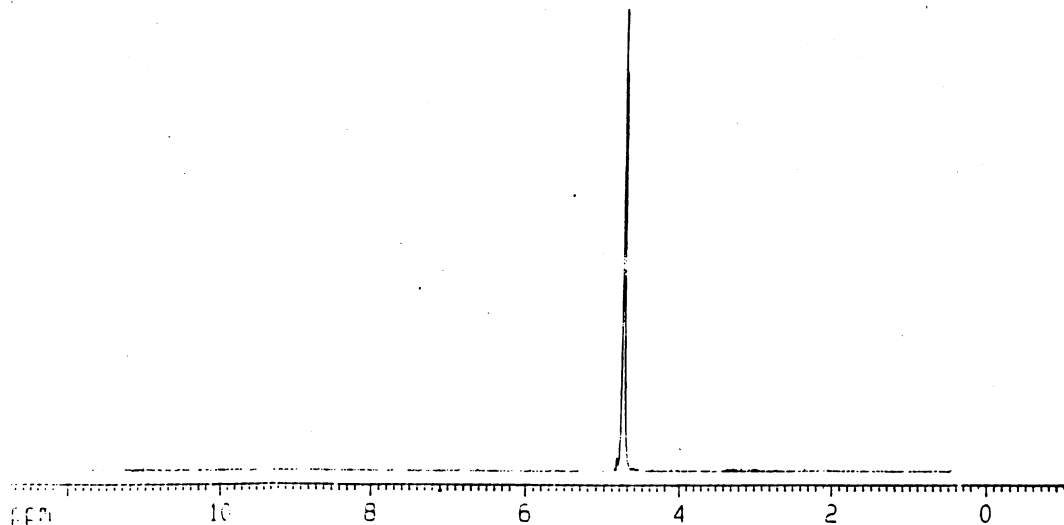
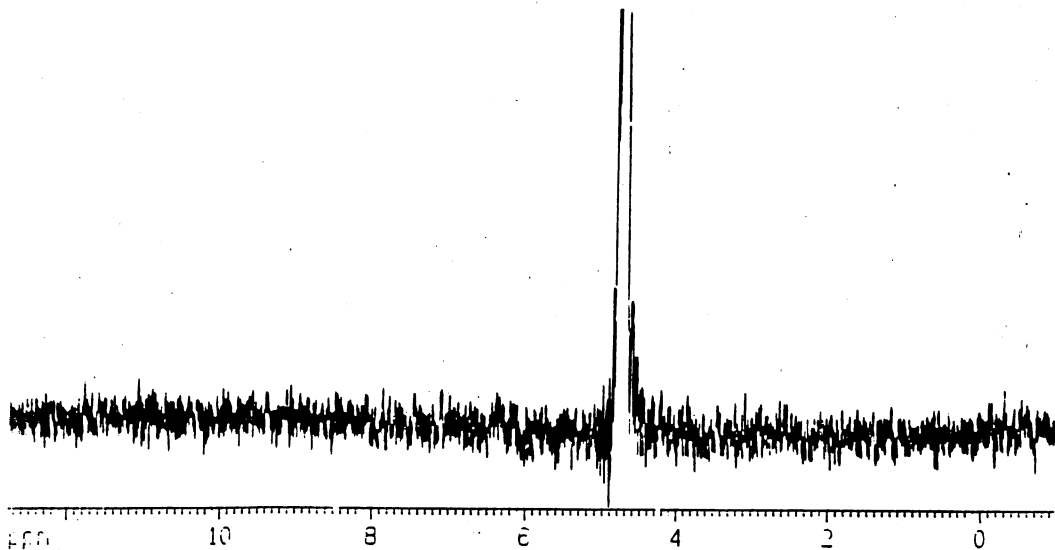
Suppression of Solvent Signal:

- samples run in water are a problem.
- water signal varies with temperature.
- irradiating the signal during recording and signal is reduced due to saturation.
- turn off decoupler right before recording and you will still get suppression due to different relaxation times of protons in the sample; water signals remain saturated.

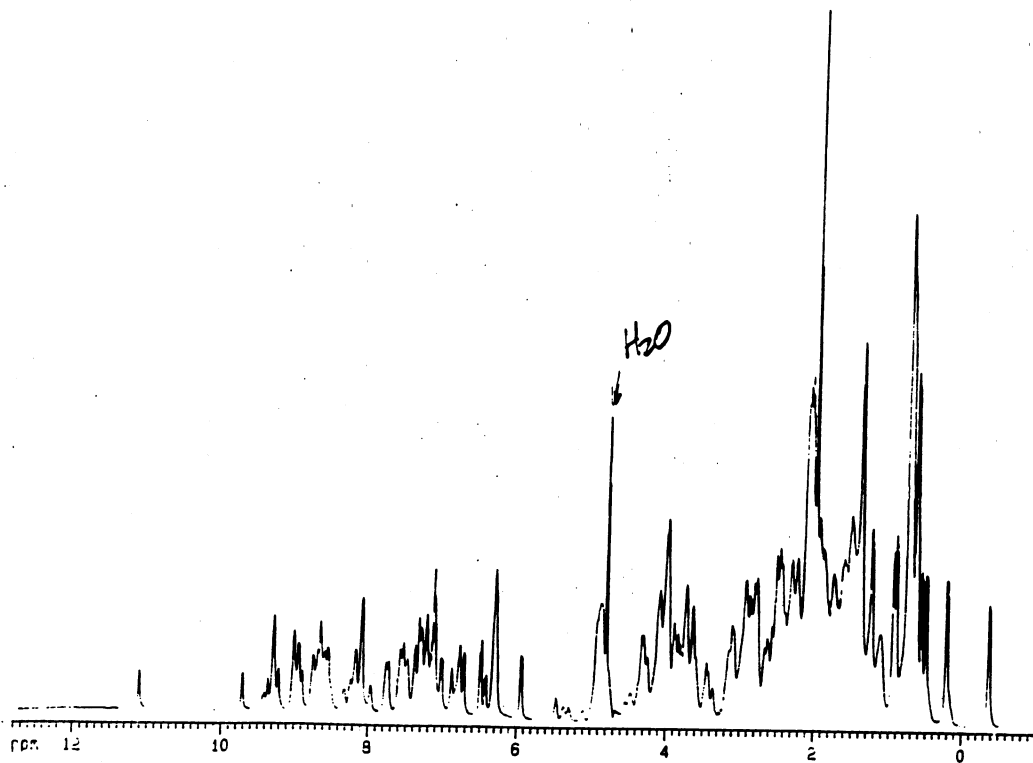


Saturation Pulse - low power, long pulse (narrow frequency band).
90 pulse - high power, short pulse (wide frequency band).
Carrier frequency (spectrometer frequency, SF) - must be on the solvent resonance.
Acquisition - AQ should be shorter than presaturation time.

¹H NMR Spectrum of Cocaine/90%H₂O without presat



¹H NMR Spectrum of Pfuore/90%H₂O at 25C



-10.00000	5.107235	46.00000	4.572339
-9.000000	5.097683	47.00000	4.562788
-8.000000	5.088131	48.00000	4.553236
-7.000000	5.078580	49.00000	4.543684
-6.000000	5.069028	50.00000	4.534133
-5.000000	5.059476	51.00000	4.524581
-4.000000	5.049924	52.00000	4.515029
-3.000000	5.040373	53.00000	4.505478
-2.000000	5.030821	54.00000	4.495926
-1.000000	5.021269	55.00000	4.486374
0.000000	5.011718	56.00000	4.476822
1.000000	5.002166	57.00000	4.467271
2.000000	4.992614	58.00000	4.457719
3.000000	4.983063	59.00000	4.448167
4.000000	4.973511	60.00000	4.438616
5.000000	4.963959	61.00000	4.429064
6.000000	4.954407	62.00000	4.419512
7.000000	4.944856	63.00000	4.409960
8.000000	4.935304	64.00000	4.400409
9.000000	4.925752	65.00000	4.390857
10.00000	4.916201	66.00000	4.381305
11.00000	4.906649	67.00000	4.371754
12.00000	4.897097	68.00000	4.362202
13.00000	4.887546	69.00000	4.352650
14.00000	4.877994	70.00000	4.343099
15.00000	4.868442	71.00000	4.333547
16.00000	4.858890	72.00000	4.323996
17.00000	4.849339	73.00000	4.314444
18.00000	4.839787	74.00000	4.304892
19.00000	4.830235	75.00000	4.295340
20.00000	4.820684	76.00000	4.285788
21.00000	4.811132	77.00000	4.276237
22.00000	4.801580	78.00000	4.266685
23.00000	4.792029	79.00000	4.257133
24.00000	4.782477	80.00000	4.247582
25.00000	4.772925	81.00000	4.238030
26.00000	4.763373	82.00000	4.228478
27.00000	4.753822	83.00000	4.218926
28.00000	4.744270	84.00000	4.209375
29.00000	4.734718	85.00000	4.199823
30.00000	4.725167	86.00000	4.190271
31.00000	4.715615	87.00000	4.180720
32.00000	4.706063	88.00000	4.171168
33.00000	4.696512	89.00000	4.161616
34.00000	4.686960	90.00000	4.152065
35.00000	4.677408	91.00000	4.142513
36.00000	4.667856	92.00000	4.132961
37.00000	4.658305	93.00000	4.123409
38.00000	4.648753	94.00000	4.113858
39.00000	4.639201	95.00000	4.104306
40.00000	4.629650	96.00000	4.094754
41.00000	4.620098	97.00000	4.085203
42.00000	4.610546	98.00000	4.075651
43.00000	4.600995	99.00000	4.066099
44.00000	4.591443	100.0000	4.056548
45.00000	4.581891		

↑
T°C

↑
ppm
from TSP

↑
T°C

↑
ppm
from TSP

chemical shift of H_2O
from TSP

.0096 ppm/or inch ON AD