STUDY-MATERIAL and REFERENCE MATERIAL

M.Sc. IV SEMESTER
PAPER-I (Spectroscopy II)
Department of Chemistry, DDU Gorakhpur University

UNIT-1 SPECTROSCOPY: ^{19}F-NMR
Fluorine-Nuclear Magnetic Resonance

^{19}F Nuclear Magnetic Resonance:

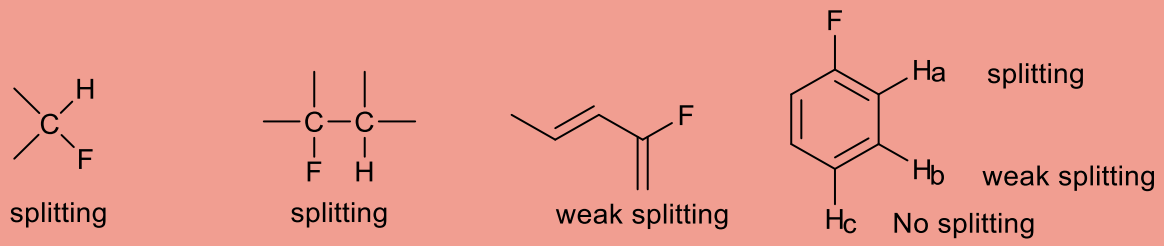
Fluorine-NMR is an analytical technique used to detect and identify fluorine containing compounds. ^{19}F is an important nucleus for NMR spectroscopy because of its receptivity and large chemical shift dispersion.

^{19}F is a naturally occurring isotope of fluorine (100 percent). A part from the provisions of an appropriate radiofrequency source (56.46 MHz at 1.4T), no major instrument modification is needed to charge NMR spectrometer from ^{1}H to ^{19}F work.

When measurements are done at same radiofrequency the signals from ^{19}F absorptions occur at considerably different magnetic field than those of protons. Thus one doesn't see peaks due to ^{19}F absorption is proton magnetic resonance.

^{19}F NMR shift span a range of ~800ppm. For organometallic compounds the range is narrower. 50 to 70 ppm (for CF_3 groups) to 200 to 220 ppm (CH_2F group). Coupling constant between fluorine nuclei cover a wider range than ^{1}HNMR.

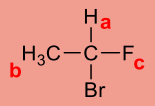
^{1}H-^{19}F Coupling:

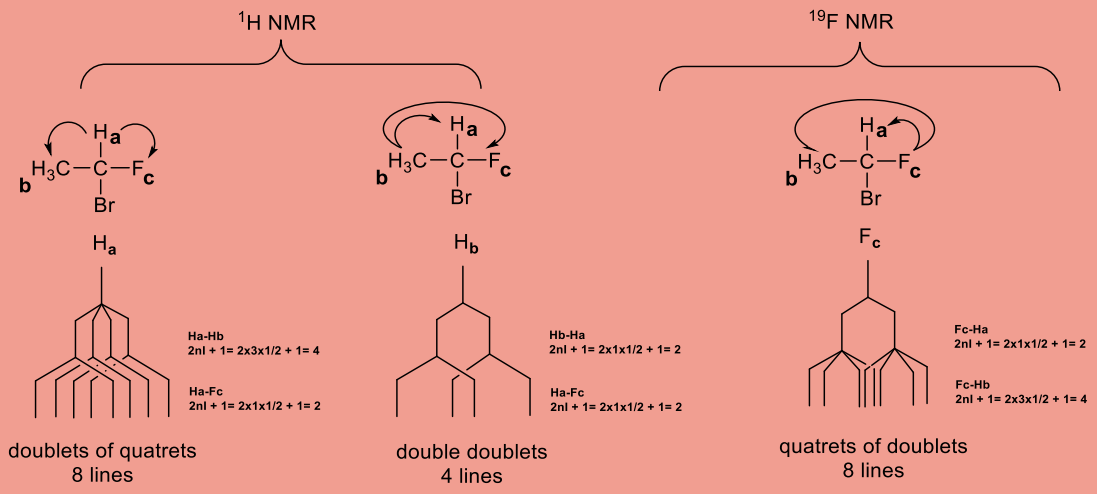


Coupling const. between fluorine cover a wider splitting range than ^{1}H NMR (see table).

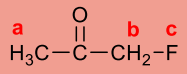
Some examples of ^{1}H and ^{19}F NMR:

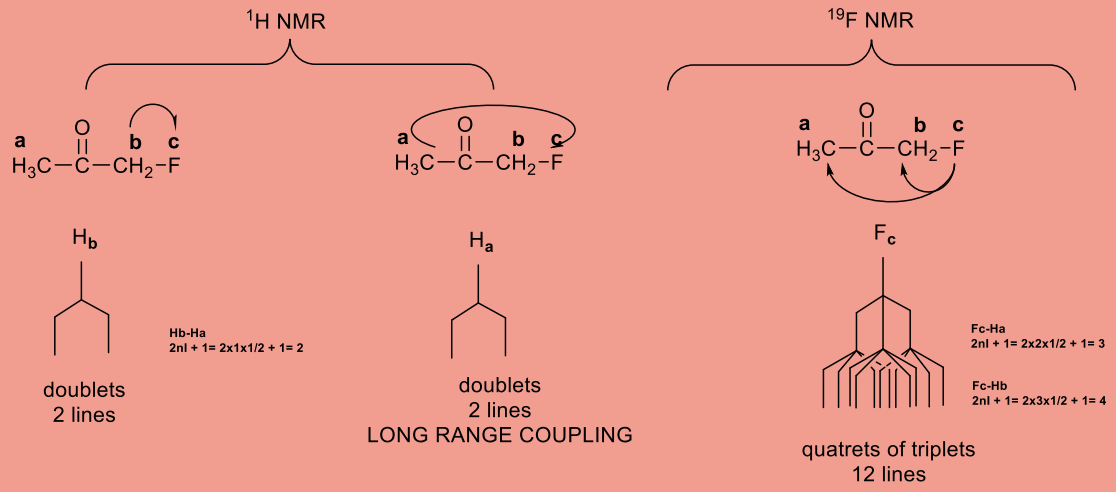
Example 1,





Example 2,

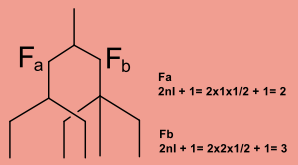




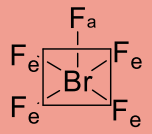
Calculate number of ^{19}F NMR peaks in following compounds :

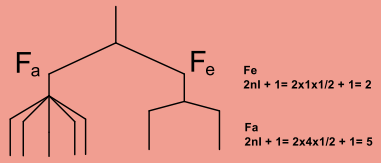
ClF_3

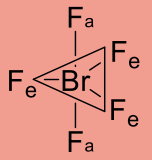
doublet, triplet

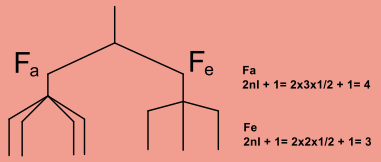


BrF_5



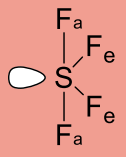




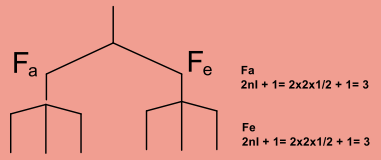


SF_4

T_d singlet (wrong)



sp^3d



Fluorine-19 nuclear magnetic resonance

- **Fluorine-19 nuclear magnetic resonance** is an analytical technique used to identify fluorine-containing compounds. ^{19}F is one of the most important nuclei for NMR spectroscopy
- ^{19}F has a nuclear spin of 1/2 and a high magnetogyric ratio, which means that this isotope is highly responsive to NMR measurements. Furthermore, ^{19}F comprises 100% of naturally-occurring fluorine.

- Because of its favorable nuclear properties and high abundance, ^{19}F NMR measurements are very fast, comparable with ^{1}H NMR spectroscopy.
- The reference compound for ^{19}F is $CFCl_3$.
- Other reference standard are given below.

^{19}F NMR Reference Standards:

Compound:	δ(ppm) vs. $CFCl_3$
$CFCl_3$ (trichloro-fluoro-methane)	0.00
CF_3COOH (trifluoro acetic acid)	-76.55
C_6F_6 (hexafluorobenzene)	-164.9
C_6H_5F (monofluorobenzene)	-113.15
CF_3Cl (trifluoro-chloro-methane)	-28.6
F_2 (elemental fluorine)	+422.92
CH_2FCN (monofluoro acetonitrile)	-251
$CFCl_2CFCl_2$ (difluoro, tetrachloroethane)	-67.80
$C_6H_5CF_3$ (trifluoro-toluene)	-63.72
SiF_4 (tetrafluorosilane)	-163.3
SF_6 (sulfur hexafluoride)	+57.42
$S_2O_5F_2$	+47.2
$(CF_3)_2CO$ (hexafluoro acetone)	-84.6
p-FC_6H_4F (para-difluorobenzene)	-106.0
BF_3	-131-3
HF (aq)	-204.0
CF_4	-62.5
Aqueous F^- (KF)	-125.3

- Positive (+) values indicate downfield shifts, lower-shielding, or higher frequency
- Negative (-) values correspond to upfield shifts, higher-shielding, or lower frequency

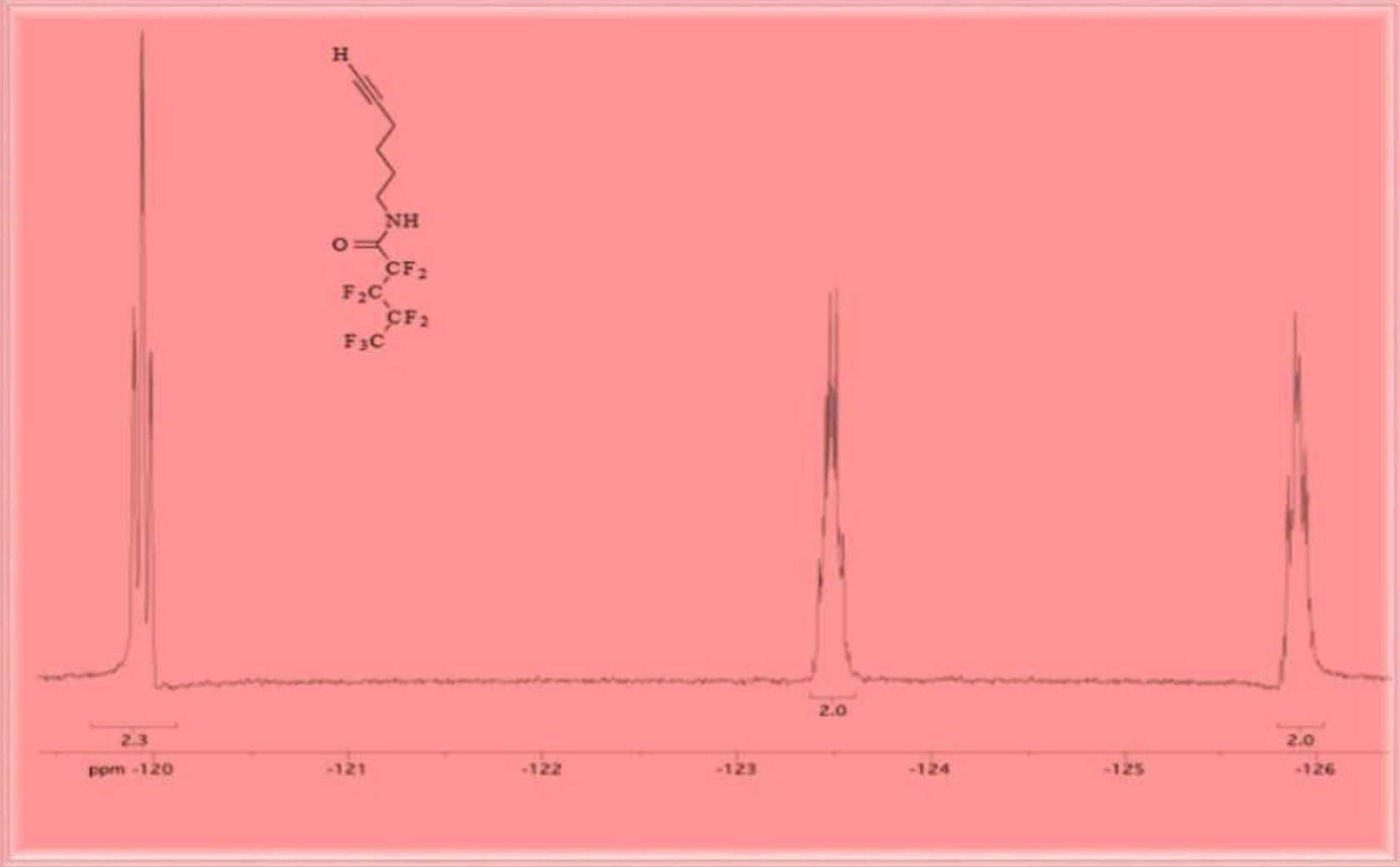
CHEMICAL SHIFT

Variation of the effective value of Bo experienced by nuclei because of their different electromagnetic environments in the molecule. Usually reported in parts per million of applied field or frequency relative to a resonance in a reference compound (eg.,$CFCl_3$).

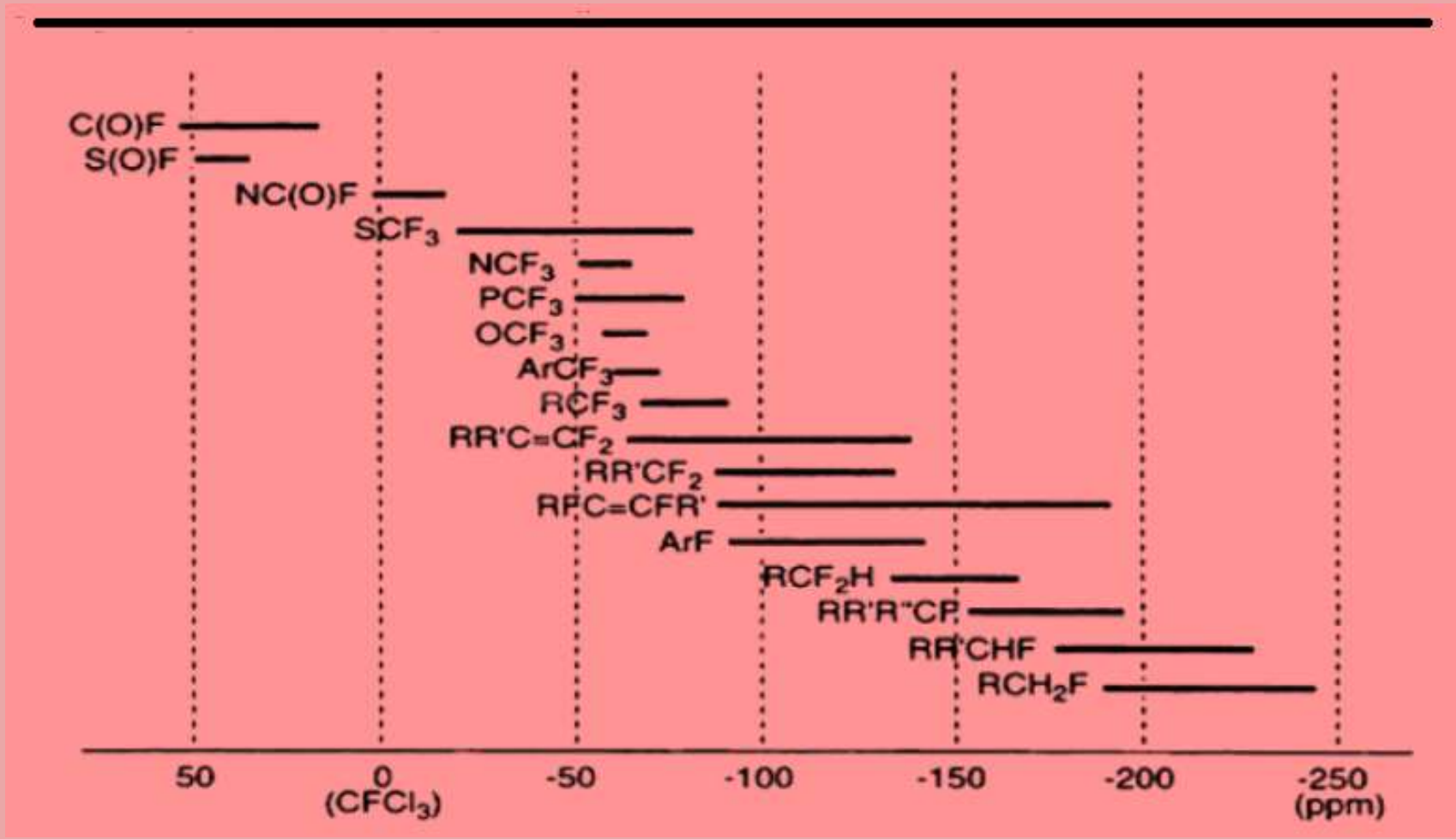
Chemical Shift of fluorine-19

- ^{19}F NMR spectra can be performed in a way equal to ^{1}H NMR. Chemical shifts of organofluorine compounds using $CFCl_3$ as standard range from 50 to -250 ppm, a maximum range is as wide 900ppm, much wider than proton NMR. Which ranges 10 to 20 ppm at best.
- ^{19}F spectra is very much more sensitive to the structural and environmental changes of molecules.

TYPICAL NMR SPECTRA OF ORGANIC FLURO COMPOUND



Typical fluorine functional groups and their chemical shift ranges are given in fig.1.15



FACTORS AFFECTING CHEMICAL SHIFTS OF FLUORINE

- Solvent effect on fluorine chemical shift
- Isotopic effect on fluorine chemical shift
- Steric de-shielding of Fluorine.

Solvent effect on fluorine chemical shift

There will usually not be much variation observed in fluorine chemical shifts for the three most common solvents used for obtaining NMR spectra, that is $CDCl_3$, DMSO-d_6 and acetone-d_6, as can be seen in the data presented in table for spectra of a series of typical fluorine containing compounds in various solvents.

Table showing solvent effect on chemical shift of fluorine

Compound	$CDCl_3$ δ	DMSO-d_6 δ	Acetone-d_6 δ	Benzene-d_6 δ	CD_3OD δ
$CF_3CHClBr$	−76.5	−75.1	−76.3	−76.6	−77.5
$HCF_2CF_2CH_2OH$	−139.2	−140.4	−141.1	−139.7	−141.8
	−127.4	−127.1	−128.5	−127.8	−129.4
fluorobenzene	−113.6	−113.1	−114.2	−113.3	−115.2
1-fluorooctane	−218.5	−216.8	−218.4	−218.2	−219.7

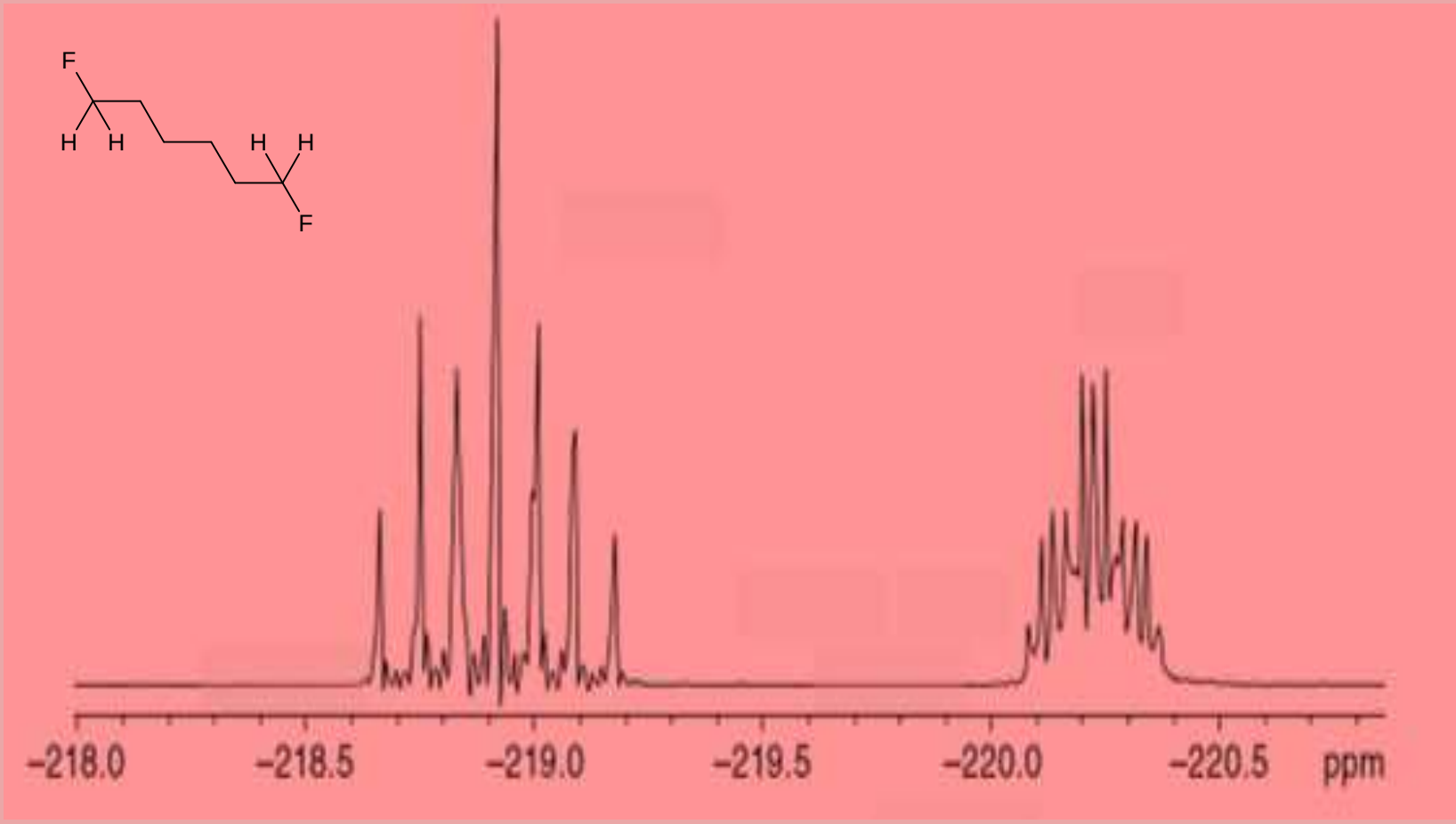
The variation in fluorine chemical shift for these three solvents is not more than + or - 1ppm.Vast majority of spectra are measured in $CDCl_3$.

Isotopic effect on fluorine chemical shift

- Because fluorine is relatively sensitive to environment and has such a larger range of chemical shifts, considerable changes in chemical shift can be observed when a nearby atom is replaced by an isotope
- For example replacement of C-12 by C-13 for the atom to which the fluorine is attached , give rise to a quite measurable shift, usually to lower frequency.

DEUTRIUM SUBSTION EFFECT

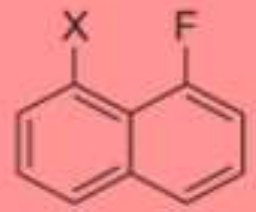
- Shifts due to either alpha or beta deutrium substitution is also quiet significant, usually leading to well resolved signals for the deutrated and undeutrated species, which can be useful in charaterization of deutrium labeled fluorinated compounds. An example of alpha effect is shown in Fig below



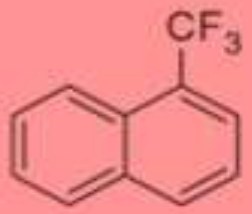
19F NMR spectrum of 1,6-difluorohexane-1,1 –D2, demonstrating the deuterium isoptopic effect on the fluorine chemical shift

STERIC DE-SHIELDING OF FLOURINE

- Another significant and not infrequently encountered impact on fluorine chemical shift is the deshielding influence of alkyl or arlyl group attached with it
- This deshielding occur only when there is direct overlap of the van der Waals radii of alkyl group and that of the fluorine , and the deshielding is thought to be result of vander Waals forces of the alkyl group restricting the motion of electrons on the fluorine and thus making the fluorine nucleus respond to the magnetic field as if the electron density were lowered.
- The most common situation where this effect is seen is in comparison of E and Z isomers of triflurомethyl or difluoromethyl substituted alkenes,



	δ_F
X = H	–124
X = CH_3	–113
X = C_2H_5	–114
X = *t*-Bu	–96



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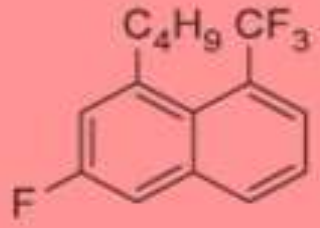

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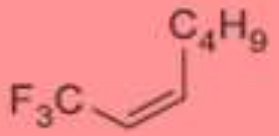
–65



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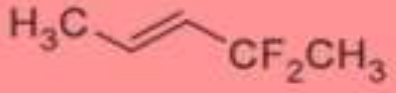

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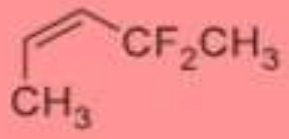
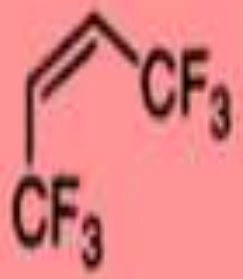


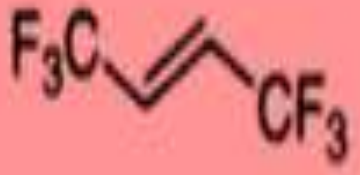
–84

Coupling constant of fluorine

- Fluorine like hydrogen gives characteristic coupling constants depending on the spacial displacement and number of bonds between a coupling partner atom.
- In particular a long range coupling J_5 is observed in an olefinic system. As shown in Fig.1.16



$^{5}J_{F\text{-}F}$ = 14 Hz



$^{5}J_{F\text{-}F}$ = 2 Hz

Fig. 1.16. Long-range F–F coupling

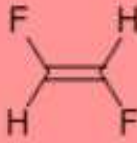
FLUORINE-FLUORINE COUPLING

- Homonuclear coupling constants between fluorine atoms are usually relatively large compared with those between hydrogen atoms,
- Coupling between germinal fluorines ($^2J_{F-F}$) also give a large value of 250 to 300Hz
- but varying greatly depending on environment of the fluorines.
- Three bond coupling $^3J_{F-F}$ in saturated aliphatic hydrocarbons are usually 15-16Hz range.but F-F coupling constant usually decreases as we increase the nuber of proximate fluorines or other electronegative substients.
- The coupling costant $^3J_{F-F}$ of trans-vic-difluoroolefin is larger than that of cis-olefin.
- The largest $^3J_{F-F}$ are observed between trans-vinyl fluorines where the coupling constant is larger than 35Hz

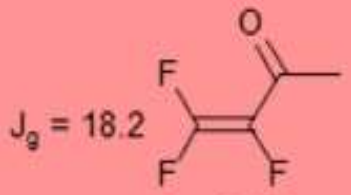
Table showing coupling J-3

	$^3J_{FH}$ (Hz)		$^3J_{FH}$ (Hz)		$^3J_{FF}$ (Hz)
$CH_3–CH_2F$	27	$CF_3–CH_3$	13	$CF_3–CH_2F$	16
$CH_3–CHF_2$	21	$CF_3–CH_2–Cl$	8.5	$CF_3–CHF_2$	3
$CH_3–CF_3$	13	$CF_3–CHCl_2$	4.7	$CF_3–CF_2–CR_3$	~0
$CH_2F–CH_2F$	17			$CF_3–CF_2–O–R$	~0
$CHF_2–CHF_2$	3			$CF_3–CF_2–S–R$	3
$CF_3–CHF_2$	3				

Fluorine-Fluorine Coupling

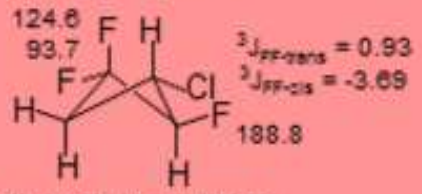
Type	Range	Examples
	$^{2}J_{FF\text{-}gem}$ 40-370 Hz	 $^{2}J_{FF\text{-}g} = 174.1$ $^{3}J_{FF} = 18.00, 18.04$
	$^{3}J_{HF\text{-}vic}$ 0-45 Hz	 $^{3}J_{FF} = -132.0$
	$^{3}J_{FF\text{-}trans}$ 100-150 Hz	 $^{3}J_{FF} = 19.1$
	$^{3}J_{FF\text{-}cis}$ 0-60 Hz	 $^{2}J_{FF} = 31.1$
	$^{2}J_{FF\text{-}gem}$ 0-110 Hz	 $J_{24} = 1.3$ $J_{26} = 2.2$ $J_{23} = 20.0$ $J_{25} = 8.6$ $J_{34} = 18.4$ $J_{35} = 1.1$
	$^{3}J_{FF\text{-}o}$ 18-35 Hz $^{4}J_{FF\text{-}m}$ 0-15 $^{5}J_{FF\text{-}p}$ 4-16	

$^{2}J_{23} = 184$
$^{3}J_{13} = 7.5$
$^{3}J_{12} = 4.9$
$^{3}J_{34} = 4.8$
$^{3}J_{24} = 2.1$



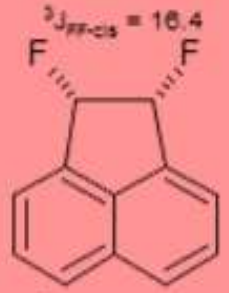
$J_g = 18.2$
$J_c = 34.6$
$J_t = 112.7$

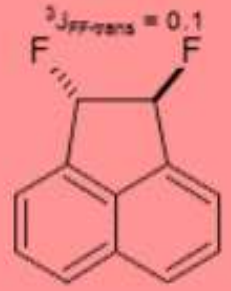
$^{2}J_{FF\text{-}gem} = 210.2$

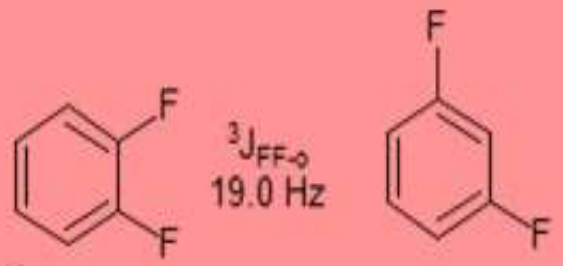


$^{3}J_{FF\text{-}trans} = 0.93$
$^{3}J_{FF\text{-}cis} = -3.69$

(all couplings available)



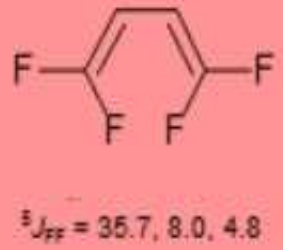



F
F
$^3J_{FF-o}$
19.0 Hz
F
F
$^4J_{FF-m}$
6.6 Hz
F
F
$^4J_{FF-p}$
17.5 Hz


$^5J_{FF}$ = 16.5
F
F


Me
Me
$^5J_{FF}$ = 170
F
F


HO
OH
Me
Me
$^5J_{FF}$ = 98
F
F

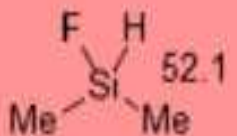
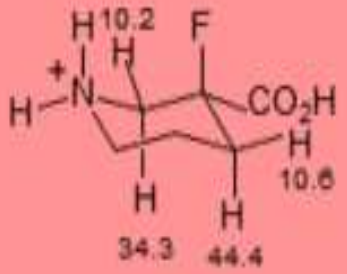
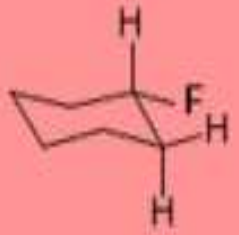

F
F
F
F
$^5J_{FF}$ = 35.7, 8.0, 4.8

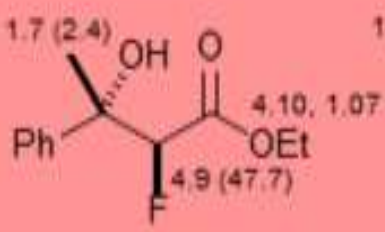
Other long range and through space homonuclear and hetronuclear couplings also observed

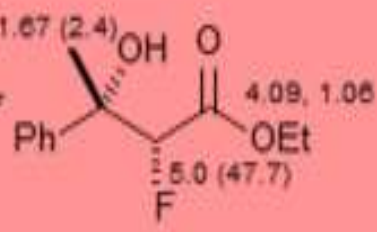
HETRONUCLEAR COUPLING H-F COUPLING

- A typical coupling of organofluorine compounds is observed in a geminal coupling ($^{2}J_{H\text{-}F}$) with a geminal hydrogen , being as large as 50Hz.
- This coupling can also be observed by proron NMR

Fluorine-Proton Coupling

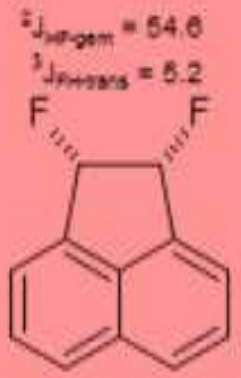
Type	Range	Examples
	$^2J_{HF\text{-}gem}$ 40-60 Hz	 $^2J_g = 48.2$ $^3J_v = 3.7, 6.2$ JA-73-182
		 $^2J_g = 56$ $^3J_c = 13.2$ $^3J_t = 1.3$
	$^2J_{HF\text{-}gem}$ 45-96 Hz	$HSiF_3$ 96.2  52.1
	$^3J_{HF\text{-}aa}$ $^3J_{HF\text{-}ae}$	 $^3J_{Fax\text{-}H}$
	$^3J_{HF\text{-}ee}$ $^3J_{HF\text{-}ea}$	

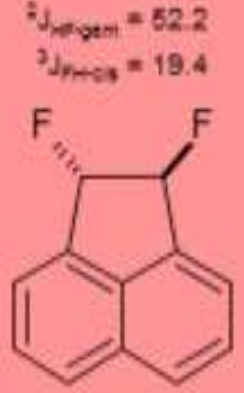




CH_3F	CH_2F_2	CHF_3
46.3	50.4	79.7

$^3J_{HF\text{-}cis} = 24.7$
$^3J_{HF\text{-}trans} = 2.0$





$^3J_{HF\text{-}trans}$
10-50 Hz

$^3J_{HF}$ = 20.3

$^3J_{HF\text{-}c}$ = 0.6
$^3J_{HF\text{-}t}$ = 34.0

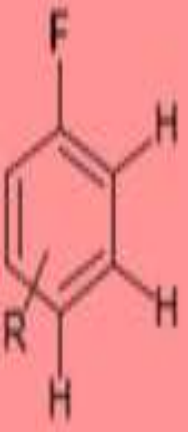
$^3J_{HF\text{-}cis}$
0-20 Hz

$^3J_{HF}$ = 3.0

$^2J_{HF\text{-}gem}$
70-90 Hz

$^2J_{HF}$ = 72.0

$^2J_{HF}$ = 75.1

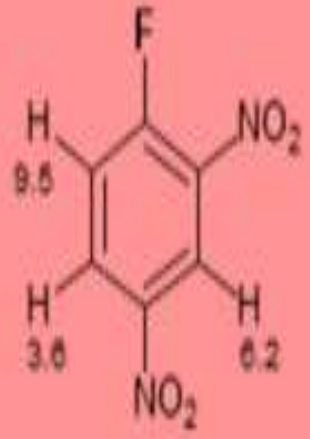


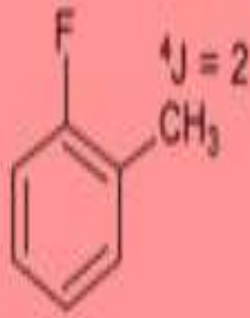
$^3J_{HF\text{-}o}$
7-12 Hz

$^4J_{HF\text{-}m}$
3.5-8 Hz

$^5J_{HF\text{-}p}$
0-3

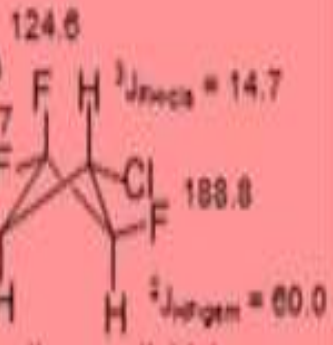
^3J_o = 8.9
^4J_m = 5.69
^5J_p = 0.22





^4J = 2

J_{a1} = 47.93
$J_{a1'}$ = 15.76
J_{a3} = 25.15
J_{a4} = +0.41
$J_{a4'}$ = +1.19



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