



A Novel *in situ* ¹⁹F NMR Thermometer

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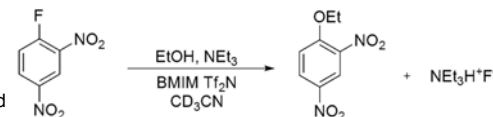


1 Introduction

For decades, the ¹H NMR spectra of methanol and ethylene glycol have been used as chemical shift thermometers,¹

i.e. they are the primary means of accurately calibrating the thermocouple in an NMR spectrometer. It has been suggested that this approach is no longer appropriate due to the strong radiation damping resulting from the high quality factor (Q) of modern cryoprobes.² Furthermore the sensitivity of any such thermometer is limited by the small chemical shift range of the ¹H nucleus. We therefore aim to develop a chemical shift thermometer based on the ¹⁹F nucleus (natural abundance 100%, relative sensitivity 0.83, strongest hydrogen bond acceptor and chemical shift range spanning 700 ppm).

While monitoring the kinetics of the aromatic substitution reaction shown above, it was observed that the chemical shift of NEt₃H⁺F⁻ varied significantly with temperature. The chemical shift of F⁻ is known to be highly dependent on solvent system,³ and we endeavour to exploit that fact and build on our initial observations in the present work.



2 Defining Sensitivity

Chemical shift thermometers relate the separation of two signals, Δδ, to the absolute temperature, T. The sensitivity, therefore, is defined as the change in absolute temperature corresponding to a fixed change in chemical shift separation:

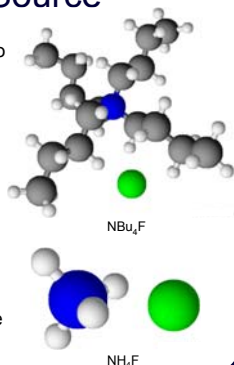
$$\text{Sensitivity} = \frac{dT}{d(\Delta\delta)}$$

The larger the numeric value of the sensitivity, the greater the jump in absolute temperature corresponding to a fixed Δδ. Hence the goal in developing a chemical shift thermometer is to *minimise* the numeric value of the sensitivity.

3 Choosing a Fluoride Source

The presence of hydrogen bound to nitrogen was seen to enhance the sensitivity of the system:

| Compound | $\frac{dT}{d(\Delta\delta)}$ |
|---------------------|------------------------------|
| NBu ₄ F | 67.6 |
| NEt ₃ HF | 9.4 |
| NH ₄ F | 5.5 |

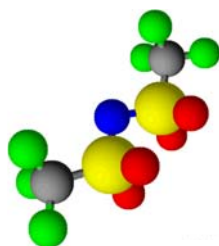


All further work was carried out using ammonium fluoride as the fluoride source.

4 Critical Components & Concentrations

BMIM Tf₂N vs. LiTf₂N as reference signal

- Ionic liquids have negligible vapour pressure
✓ Easy storage
- Unlike LiTf₂N, BMIM Tf₂N has considerable presence in ¹H spectrum
 - ✗ Obscures analyte signals
- LiTf₂N instead of BMIM Tf₂N almost doubles the sensitivity!



Bistriflimide anion, Tf₂N⁻

EtOH vs. CD₃CN

- Sensitivity ∝ [CD₃CN]
- NH₄F insoluble in CD₃CN
∴ minimum [EtOH] determined by acceptable signal:noise

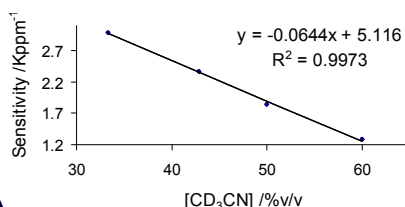


Figure 1. Sensitivity as a function of [CD₃CN]

5 Results to Date

¹⁹F Thermometer

- 3.4 mg LiTf₂N
- 300 μL CD₃CN
- 300 μL sat. solution of NH₄F in EtOH

Properties

- Operating range: 213 – 343 K
 - Linear fit for T < 270 K
 - Quadratic fit for T > 270 K
- Sensitivity:
 - < 270 K ~22
 - > 270 K (see Figure 3)

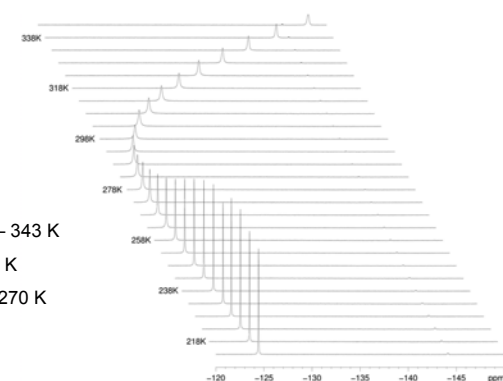


Figure 2. Variation in the chemical shift of F⁻ with temperature (NH₄F)

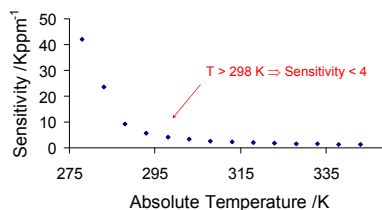


Figure 3. Variation in sensitivity of ¹⁹F thermometer for T > 270 K

| Existing System | Nucleus | $\frac{dT}{d(\Delta\delta)}$ |
|--|---------------------------------|------------------------------|
| MeOH | ¹ H / ² H | 143 ^{1,4} |
| CHCl ₂ F, C ₆ F ₆ , d ₈ -toluene | ¹⁹ F | 90 ⁴ |
| CH ₃ I, TMS | ¹³ C | 29 ⁴ |
| Xe(g) in CDCl ₃ | ¹²⁹ Xe | 2.6 ⁵ |

6 Conclusions and Future Work

Advantages

- Exhibits higher sensitivity than many existing methods
- Use of deuterated solvents results in minimal interference with signals of interest (¹H NMR spectrum)
- Operating range of 130 K

Disadvantages

- Current system not modelled well by single function over whole temperature range
- Low signal:noise (solubility)
- Line broadening at high temperatures
- Sensitivity of F⁻ to moisture content
- Etching of NMR tube over time (HF)

Future Investigations

- Repeat experiments using anhydrous solvents (K.F. titration to monitor [H₂O])
→ chemical shift of F⁻ highly dependent on solvent system
- Explore alternative solvent systems e.g. MeOH, propanol, DME
→ initial studies indicate MeOH an order of magnitude less sensitive than EtOH
- Explore alternative co-solvent e.g. d₆-acetone, pyridine, DMF
→ initial studies indicate d₆-acetone less sensitive than CD₃CN
- Explore alternative reference signals e.g. SiF₆²⁻, CF₃CD₂OD

References

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