

Strength of Cations in Different types of N-Containing bases

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Abstract- Using selected theoretical methods the affinity of a large range of bases towards model cations has been quantified. The range of model cations includes the methyl cation as the smallest carbon-centered electrophile, the benzhydryl and trityl cations as models for electrophilic substrates encountered in base-catalyzed synthetic procedures, and the acetyl cation as a substrate model for acyl-transfer reactions. Affinities towards these cationic electrophiles are complemented by data for base addition to Michael acceptors as prototypical neutral electrophiles.

I. INTRODUCTION

Cation affinity values are important guidelines for the reactivity of Lewis and Brønsted bases [1-3]. While proton affinity numbers (either as gas phase proton affinities or as solution phase pK_a values) have been used for a long time in quantitative approaches to describe base-induced or base-catalyzed processes, affinity data towards carbon electrophiles have only recently been adopted as tools for the assessment of Lewis base reactivity [4]. This is mainly due to the scarcity of accurate experimentally measured or theoretically calculated

data. The performance of various theoretical methods to provide accurate affinity data has recently been analyzed and a number of cost efficient methods for the determination of accurate gas phase values have been identified [5,6]. Using these methods we now present a broad overview over the cation affinities of N-Centered nucleophiles.

II. RESULTS AND DISCUSSION

Methyl cation affinities (MCA) The methyl cation (CH_3^+) is the smallest carbocation which is Useful as a chemical probe for Lewis bases. The respective methyl cation affinity of a given Lewis base (LB) is obtained as the reaction enthalpy at 298.15 K and 1 bar pressure for the reaction shown in equation 1a for a neutral Lewis base and in equation 1b for an anionic base (Scheme 1). This definition is in analogy to that for proton affinities (PA) and implies large positive energies for most of the N-based Lewis bases used in catalytic processes. Using pyridine (1) as an example for a weak Lewis base, the methyl cation affinity corresponds to the enthalpy of the reaction in equation 1c and amounts to $\text{MCA}(\mathbf{1}) = +519.2 \text{ kJ/mol}$ at the G3 level of theory [5].

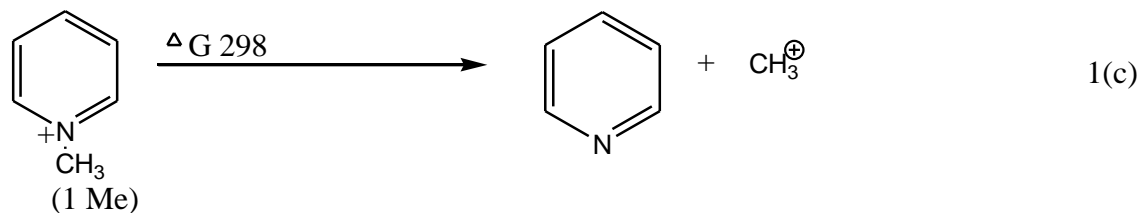

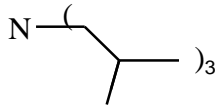

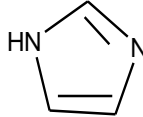
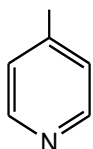
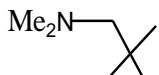
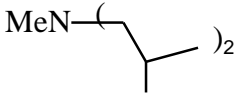
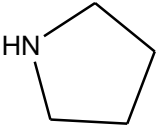
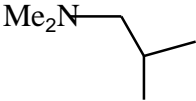


Table 1: MCA values for N-centered Lewis bases, ordered by increasing MCA values.

| System | Number | MCA [kJ/mol] |
|---|--------|--------------|
| NH ₃ | (2) | +436.4 |
| NH ₂ Me | (3) | +487.7 |
| NMePh ₂ | (4) | +513.4 |
| pyridine | (1) | +519.7 |
| N _c -Pr ₃ | (5) | +520.2 |
|  | (6) | +522.6 |
| NHMe ₂ | (7) | +522.1 |
| NMec-Pr ₂ | (8) | +523.3 |
| NMe ₂ Ph | (9) | +527.0 |
|  | (10) | +528.4 |
|  | (11) | +530.1 |
|  | (12) | +531.7 |
| NMe ₂ <i>c</i> -Pr | (13) | +531.9 |
|  | (14) | +532.7 |
|  | (15) | +535.8 |

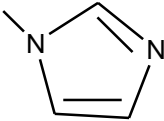
| | | |
|---|------|--------|
| $N(iPr)_3$ | (16) | +536.0 |
|  | (17) | +538.1 |
|  | (18) | +539.8 |
|  | (19) | +541.3 |
| NMe_3 | (20) | +543.3 |

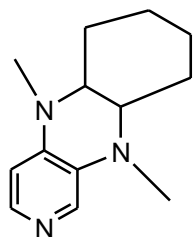
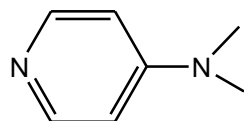
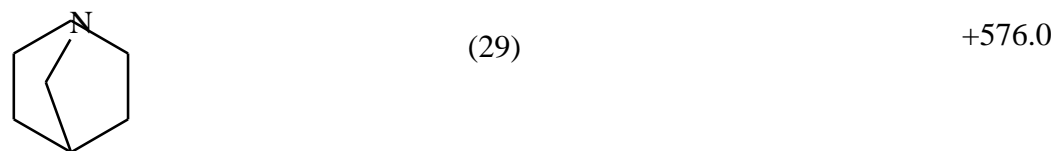
Scheme 1: Reactions for the methyl cation affinity (MCA) of a neutral Lewis base (1a), an anionic Lewis base (1b) and pyridine (1c). A recent analysis of theoretical methods found that calculations at the MP2(FC)/6-31+G(2d,p)//B98/6-31G(d) level of theory (in short: "MP2-5") reproduce results obtained at the G3 level within 4.0 kJ/mol for selected small and medium-sized organo catalysts [5]. For pyridine (1) the MCA value obtained with this model amounts to MCA (1) = +518.7 kJ/mol, which is only 0.5 kJ/mol lower than the G3 value. The following discussion will thus be based on results obtained with the MP2-

5model, if not noted otherwise. Methyl cation affinity values obtained for N-centered Lewis bases using this approach are collected in Table 1. For organo catalytic processes especially the Lewis bases **12**, **14**, **18**, **24**, note.

Pyridine is a comparatively weak nucleophile as already mentioned above. This also applies to imidazole (**12**), pyrrolidine (**18**) and a number of trialkylamines, all of which have MCA values below 550 kJ/mol. In the case of pyridine it is possible to increase the Lewis basicity by introducing electron

Table 1: MCA values for N-centered Lewis bases, ordered by increasing MCA values. (Continued)

| | | |
|--|------|--------|
| $Nt-Bu_3$ | (21) | +545.5 |
| NMe_2Et | (22) | +548.6 |
| NMe_t-Bu_2 | (23) | +549.4 |
|  | (24) | +550.0 |
| NMe_2c-Bu | (25) | +551.0 |
| $NMe_2(iPr)$ | (26) | +551.3 |
| NMe_2n-Pr | (27) | +551.9 |



III. TECHNICAL ASPECTS

It was shown recently that MCA values can be calculated with high accuracy with methods like G2, G3 or W1 [5]. Beside these expensive methods some MP2 calculations can also afford, slightly less, accurate results. For the MP2 calculations different combinations of polarization functions and diffuse functions were tested. In contrast, DFT methods such as B3LYP seem to be unsuitable for predicting MCA values in an adequate manner. A good compromise between computational effort and predictive value was found for the MP2(FC)/6-31+G(2d,p)//

B98/6-31G(d) level of theory. Therefore, all results described in this publication have been obtained using this approach. Despite the fact that all affinity definitions in equations 1, 5, 6, 8–10 use the separate reactants as the thermochemical reference state, for most applications in synthesis and

catalysis it is absolutely sufficient to consider differences in cation affinities between two different Lewis bases.

IV. CONCLUSION

Affinity data towards selected electrophiles provide the means to quantify Lewis bases with respect to their carbon basicity. This complements the limited amount of experimental affinity data and provides a quantitative guideline in catalyst development projects in which the addition of Lewis bases to carbon electrophiles represents the key step of the catalytic cycle.

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