

1,3,4-Triphenyl-4,5-dihydro-1H-1,2,4-triazol-5-ylidene – Applications of a Stable Carbene in Synthesis and Catalysis

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Dedicated to Professor Ekkehard Winterfeldt on the Occasion of his 65th Birthday

Carbenes belong to the most important reactive intermediates in organic synthesis, bearing a divalent carbon atom as common structural feature. Due to their pronounced reactivity they proved to be notoriously evasive [1]. However, a few groups recently managed to prepare carbenes, that are stable in the absence of oxygen and moisture [2, 3], leading to a major renaissance of the chemistry of nucleophilic carbenes [4]. A member of this remarkable class of compounds is the title compound 1,3,4-triphenyl-4,5-dihydro-1H-1,2,4-triazol-5-ylidene (**1**) which shows the reactivity typical of nucleophilic *Wanzlick*-type carbenes [5].

Preparation of the stable carbene

The carbene **1** can be easily prepared in quantitative yield from 5-methoxy-1,3,4-triphenyl-4,5-dihydro-1H-1,2,4-triazolin (**2**) by simple thermal decomposition *in vacuo* via α -elimination of methanol (pathway A, scheme 1) [3, 5]. In terms of simplicity, this procedure is clearly superior to the common techniques for the preparation of stable carbenes involving the use of strong bases or potassium [2]. The obtained carbene is an infinitely stable solid (m.p. 15 °C) if exposure to oxygen and moisture is avoided. However, **1** can also be generated from **2** *in situ* by simply refluxing a solution of **2** in absolute toluene in the presence of the respective substrate (pathway B, scheme 1)

[3]. In some cases this procedure proved superior to the direct use of **1**.

The methoxytriazoline itself is available *via* addition of methoxide [3] to the corresponding 1,3,4-triphenyl-1,2,4-triazolium salt [6].

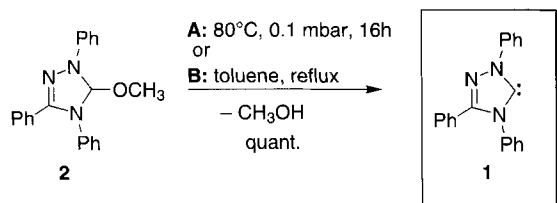
Triazol-5-ylidene **1** as a typical carbene representative

Carbene **1** readily inserts into the OH, SH and NH bonds of alcohols, thiols and amines, respectively, yielding the corresponding alkoxy-, alkylthio- or alkylaminotriazolines **3**. The reaction with chalcogens such as oxygen, sulphur and selenium gives the triazolone-, -thione and -selenone **4**, respectively, in good yields (scheme 2) [5].

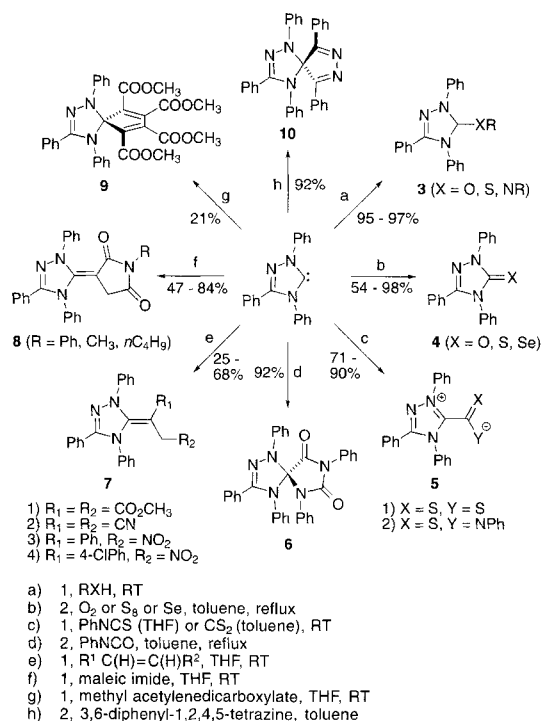
The reaction of **1** with heterocumulenes such as phenylisothiocyanates and carbonyl disulphide affords the corresponding betaines **5** in very good yields, which could be used as 1,3-dipolar synthons in the synthesis of thiohydantoins and dithiols *via* [3+2]-cycloaddition [7]. However, upon treatment of **1** with phenylisocyanate the intermediate dipole rapidly reacts further with excess PhNCO in a [3+2]-cycloaddition furnishing the hydantoin **6** in good yield (scheme 2) [5]. A similar pathway was earlier used to open up an access to parabanic acid derivatives [8].

1 reacts with doubly activated double bonds such as fumaric and maleic esters, nitriles, maleic imides and nitro olefines, affording the respective open-chain allylic systems **7** and **8** (scheme 2), which are possibly formed *via* ring opening of the corresponding cyclopropanes. Compounds **7** and **8** are characterized by a very low barrier for the rotation round the C=C double bond, leading to the virtually unhindered rotation observed at room temperature [5].

Furthermore, the addition of carbene **1** to methyl acetylenedicarboxylate lead to the formation of the spirocyclic compound **9** *via* a Michael-type addition pathway with subsequent 1,3-dipolar cycloaddition. Reaction of the triazol-5-



Scheme 1



Scheme 2

ylidene **1** with an electron-deficient diene such as 3,6-diphenyl-1,2,4,5-tetrazine gave the *spiro* system **10** via [4+1]-cycloaddition with subsequent *retro*-Diels-Alder-type extrusion of nitrogen (scheme 2) [5].

Application of the Carbene as Ligand in Organometallic and Inorganic Chemistry

Recent research has shown that Wanzlick-type carbenes (e.g. **1**) can be used as promising substitutes for phosphane ligands in organometallic chemistry, since the resultant complexes proved to be considerably more stable than their phosphane analogues [9]. Analogously, carbene **1** can be readily introduced into carbonyl complexes *via* thermochemical ligand substitution as was exemplified by the preparation of the carbene complexes **11** of chromium and molybdenum (scheme 3) [10]. Furthermore, triazol-5-ylidene **1** smoothly reacts with $\text{BH}_3 \cdot \text{THF}$ complex yielding the carbene- BH_3 adduct **12**, which amply illustrates the potential of the carbene as a typical Lewis base (scheme 3) [5].

Application of the Stable Carbene in Organic Catalysis

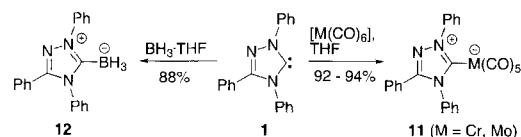
Beside its exciting carbene chemistry, triazol-5-ylidene **1** turned out to be a powerful catalyst for the condensation of formaldehyde yielding glycolaldehyde **13** with good yields and selectivities (scheme 4) [6]. This reactivity complements the catalytic properties of thiazolium salts, which have been known for a long time to catalyze the formoin reaction affording 1,3-dihydroxyacetone as product [11]. As compared with thiazolium salts, carbene **1** is much more stable when exposed to traces of water and oxygen at elevated temperatures, allowing total turnover numbers as high as 14 000. However,

the applicability of carbene **1** is not merely limited to this substrate. It can also be used for the catalytic generation of benzoin and acyloins **14** when the respective aromatic and aliphatic aldehydes are used as substrates [12].

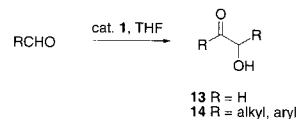
Chiral analogues of the triazol-5-ylidene **1** have been used as catalysts for asymmetric variants of the benzoin and Stetter reaction [13].

Conclusion

In conclusion, the stable carbene **1** offers an easy access to the dynamic field of the chemistry of nucleophilic carbenes. A wide variety of organic and organometallic applications are feasible, many others can be imagined. In addition, the carbene **1** is a powerful catalyst for formoin, acyloin and benzoin-type condensations.



Scheme 3



Scheme 4

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