

# Synthesis, Characterization and Catalytic Properties of Cationic N-Heterocyclic Carbene Copper(I) Complex

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## Abstract

A cationic N-heterocyclic carbene copper(I) complex was prepared and characterized by FT-IR, <sup>1</sup>H NMR, <sup>13</sup>C NMR, elemental analysis and ESI/TOF mass spectrometry methods. Catalytic performances of the complex were studied in the [3+2] cycloaddition reaction of some azides and alkynes.

**Keywords:** N-heterocyclic carbene, copper(I), benzimidazol-2-ylidene, azide-alkyne cycloaddition.

## 1. Introduction

N-heterocyclic carbene (NHC) metal complexes are organometallic compounds which have strong metal-carbon bonds due to strong nucleophilic character of NHC ligands. Their transition metal complexes have wide usage in organometallic chemistry. The first NHC-Cu(I) compound was prepared by the reaction of free 1,3-dimesitylimidazol-2-ylidene and copper(I) triflate in 1993 [1]. They have exhibited catalytic efficiencies in many reactions such as hydrosilylation [2], allylic substitution [3], addition of S-H bonds to olefins [4], hydroboration [5] and carboxylation of organoboronic acid esters etc. [6].

[3+2] cycloaddition of azides and alkynes gives 1,2,3-triazoles widely employed in medicinal chemistry [7, 8]. When this reaction proceeds with a copper(I) catalyst, 1,4-disubstituted-1H-1,2,3-triazole regioisomer is formed without byproduct. Various copper species have served as active catalysts in this transformation [9-12]. Also, NHC copper(I) complexes have led to 1,2,3-triazoles [13].

In this paper, preparation of a cationic NHC copper(I) complex and preliminary catalytic tests in azide-alkyne cycloaddition reactions are reported. The structure of the Cu(I) complex is defined by FT-IR, <sup>1</sup>H NMR, <sup>13</sup>C NMR, ESI/TOF mass spectrometry and elemental analysis methods. The catalytic products are characterized by <sup>1</sup>H NMR and <sup>13</sup>C NMR analyses.

## 2. Materials and Methods

### 2.1. General Considerations

The synthesis of copper(I) complex was performed under argon atmosphere using flame-dried schlenk. **1** was synthesized according to a reported study by precipitating the product without removing of the solvent [14]. Ethyl 2-azidoacetate and phenyl azide were

prepared by using of the literature methods [15, 16]. THF and hexane were used after drying with suitable agents. The other solvents and the reagents were used without any purification. Elemental analysis was performed using a CHNS-932 (LECO) elemental analyzer. For <sup>1</sup>H NMR and <sup>13</sup>C NMR analyses, Varian 400 MHz NMR spectrophotometer was employed. FT-IR spectrum was monitored on Perkin Elmer spectrophotometer at a range of 400-4000 cm<sup>-1</sup>. Molecular weight of the complex was determined by Bruker Daltonics MicroTof II instrument. Melting point measurement was made in a glass capillary tube under argon with Electrothermal 9100 apparatus.

### 2.2. Synthesis of NHC-Cu(I) complex (**2**)

A mixture of **1** (326 mg, 0.54 mmol), [Cu(CH<sub>3</sub>CN)<sub>4</sub>]BF<sub>4</sub> (85 mg, 0.27 mmol) and NaOBu<sup>t</sup> (52 mg, 0.54 mmol) in THF (20 mL) was stirred for 24h at room temperature. After filtration through a plug of Celite, THF was removed under vacuum. The residue was crystallized from n-hexane at +4 °C. Yield: 0.29 g, 92%. mp: 222-223 °C. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>): δ = 7.17-6.99 (m, 20H, Ar-H), 5.62 (s, 8H, NCH<sub>2</sub>), 1.08 (s, 72H, CH<sub>3</sub>) ppm. <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ = 151.29, 135.59, 134.64, 122.85, 122.05, 111.79, 53.55, 34.93, 31.61 ppm. <sup>19</sup>F NMR (100 MHz, CDCl<sub>3</sub>): δ = 114.24 ppm. FT-IR (KBr) ν(C=N): 1394 cm<sup>-1</sup>. ESI/TOF MS: [M-PF<sub>6</sub>-H] at m/z 1107.7. Anal. Calc. for C<sub>74</sub>H<sub>100</sub>N<sub>4</sub>CuBF<sub>4</sub>: C, 74.31; H, 8.43; N 4.69. Found: C, 71.68; H, 8.21; N, 4.44%.

### 2.3. General procedure for [3+2] cycloaddition of azides and alkynes

Azide (1.0 mmol), alkyne (1.1 mmol) and the catalyst (1.0 mol% or 0.5 mol%) were put in a test tube with a lid. The mixture was stirred until the solidification was observed. It was dissolved in CH<sub>2</sub>Cl<sub>2</sub> and n-pentane was added. The product was isolated by filtration, washing with n-pentane and drying under reduced pressure. The

products, present compounds in the literature, were determined by  $^1\text{H}$  NMR and  $^{13}\text{C}$  NMR analyses [17-19].

#### Ethyl 2-(4-phenyl-1H-1,2,3-triazol-1-yl)acetate

$^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  = 7.98 (s, 1H, triazole), 7.85 (d,  $J$  = 7.08 Hz, 2H, Ar-H), 7.42 (t,  $J$  = 7.12 Hz, 2H, Ar-H), 7.33 (t,  $J$  = 7.34 Hz, 1H, Ar-H), 5.18 (s, 2H,  $\text{NCH}_2$ ), 4.26 (q,  $J$  = 7.14 Hz, 2H,  $\text{CO}_2\text{CH}_2\text{CH}_3$ ), 1.29 (t,  $J$  = 7.13 Hz, 3H,  $\text{CO}_2\text{CH}_2\text{CH}_3$ ) ppm.  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  = 166.49, 159.17, 130.75, 129.05, 125.97, 99.11, 62.62, 51.27, 14.27 ppm.

#### Ethyl 2-(4-butyl-1H-1,2,3-triazol-1-yl)acetate

$^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  = 7.47 (s, 1H, triazole), 5.11 (s, 2H,  $\text{NCH}_2$ ), 4.24 (q,  $J$  = 7.15 Hz, 2H,  $\text{CO}_2\text{CH}_2\text{CH}_3$ ), 2.75-2.71 (m, 2H,  $\text{CH}_2$ ), 1.69-1.66 (m, 2H,  $\text{CH}_2$ ), 1.43-1.34 (m, 2H,  $\text{CH}_2$ ), 1.28 (t,  $J$  = 7.13 Hz, 3H,  $\text{CO}_2\text{CH}_2\text{CH}_3$ ), 0.92 (t,  $J$  = 7.31 Hz, 3H,  $\text{CH}_3$ ) ppm.  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  = 166.69, 109.99, 62.47, 51.00, 31.63, 25.52, 22.45, 14.24, 13.98 ppm.

#### 1-benzyl-4-phenyl-1H-1,2,3-triazole

$^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  = 7.81 (d,  $J$  = 7.28 Hz, 2H, Ar-H), 7.71 (s, 1H, triazole), 7.41-7.28 (m, 8H, Ar-H), 5.54 (s, 2H,  $\text{NCH}_2$ ) ppm.  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  = 134.99, 130.88, 129.34, 129.04, 128.96, 128.37, 128.26, 125.91, 54.43 ppm.

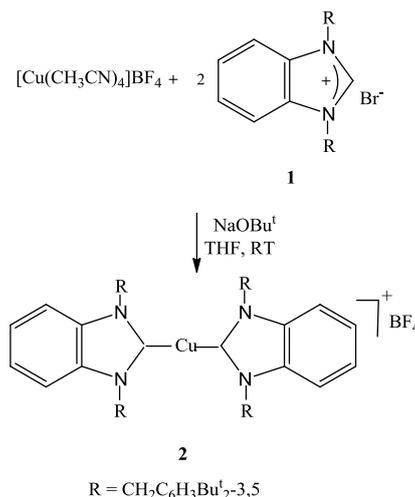
#### 1,4-diphenyl-1H-1,2,3-triazole

$^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ ):  $\delta$  = 8.19 (s, 1H, triazole), 7.92 (d,  $J$  = 7.20 Hz, 2H, Ar-H), 7.80 (d,  $J$  = 7.51 Hz, 2H, Ar-H), 7.57-7.53 (m, 2H, Ar-H), 7.48-7.45 (m, 3H, Ar-H), 7.39-7.35 (m, 1H, Ar-H) ppm.  $^{13}\text{C}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  = 148.65, 137.33, 130.50, 129.99, 129.13, 128.98, 128.64, 126.09, 120.76, 117.81 ppm.

### 3. Results and Discussion

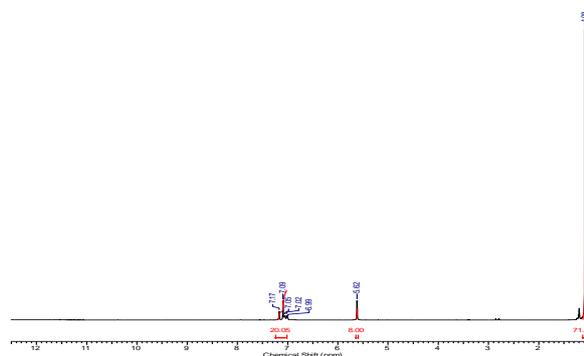
Synthesis of NHC copper(I) complex is shown in scheme 1. The reaction of  $[\text{Cu}(\text{CH}_3\text{CN})_4]\text{BF}_4$  with two equivalents of the benzimidazolium salt **1** in the presence of  $\text{NaOBu}^t$  gave the cationic bis(NHC) copper(I) complex in 92% yield. The compound is soluble in  $\text{CH}_2\text{Cl}_2$ , THF, toluene, DMSO and DMF and insoluble in  $\text{Et}_2\text{O}$  and  $n$ -pentane.

Structure of the compound was elucidated by  $^1\text{H}$  NMR,  $^{13}\text{C}$  NMR, FT-IR, elemental analysis and ESI/TOF mass methods. Unfortunately, a single crystal could not be obtained for x-ray diffraction analysis despite all our efforts. In the  $^1\text{H}$  NMR spectrum, absence of the peak related to the acidic NCHN proton is an evidence for formation of a carbene complex (Figure 1). Singlet signals present at 5.62 and 1.08 ppm in the  $^1\text{H}$  NMR spectrum refer to the methylene protons and  $\text{Bu}^t$  protons, respectively.

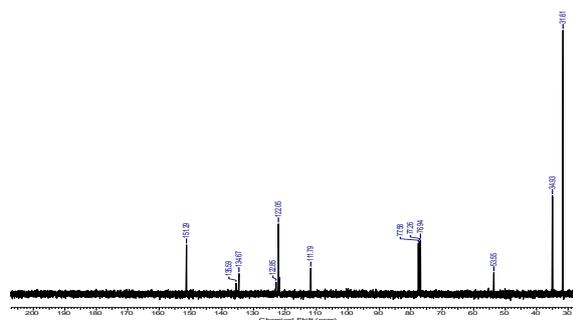


**Scheme 1.** Synthesis of the copper(I) complex.

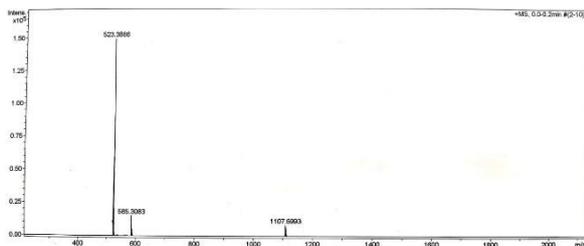
In the  $^{13}\text{C}$  NMR spectrum, chemical shift values for methylene and  $\text{Bu}^t$  groups are 53.55, 34.93 and 31.61 ppm (Figure 2).  $\text{C}_{\text{carbene}}$  chemical shift is not observed in the  $^{13}\text{C}$  NMR spectrum. This situation has been previously reported [20]. The peaks existing at 2962  $\text{cm}^{-1}$  and 1394  $\text{cm}^{-1}$  are related to the stretching vibrations of the  $\text{Bu}^t$  group and  $-\text{C}=\text{N}-$  groups in the FT-IR spectrum [14]. The ESI/TOF mass spectrum affirms the formation of  $[(\text{NHC})_2\text{Cu}]^+$  ion (Figure 3).



**Figure 1.**  $^1\text{H}$  NMR spectrum of the copper(I) complex.

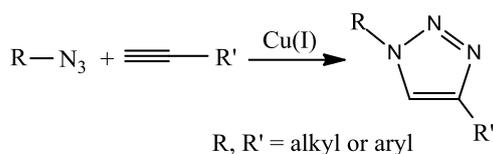


**Figure 2.**  $^{13}\text{C}$  NMR spectrum of the copper(I) complex.



**Figure 3.** ESI/TOF mass spectrum of the copper(I) complex.

**Table 1.** NHC-copper(I) catalyzed [3+2] cycloaddition of some azides and alkynes <sup>a</sup>



Entry	R	R'	Time (min)	Yield (%)
1	CH <sub>2</sub> CO <sub>2</sub> Et	Ph	25	61 <sup>b</sup>
2	CH <sub>2</sub> CO <sub>2</sub> Et	Ph	10	92
3	CH <sub>2</sub> CO <sub>2</sub> Et	n-Bu	330	95
4	Bn	Ph	60	74
5	Ph	Ph	15	88

<sup>a</sup> Reaction conditions: 1.0 mmol azide, 1.1 mmol alkyne, NHC-Cu(I) catalyst (1 mol%), RT. <sup>b</sup>NHC-Cu(I) catalyst (0.5 mol%).

The reaction of ethyl 2-azidoacetate and phenylacetylene to give 2-(4-phenyl-1H-1,2,3-triazol-1-yl)acetate was realised using 1mol% and 0.5 mol% catalyst at room temperature (Table 1, entries 1, 2). High yield was obtained with 1 mol% catalyst in a short time of 10 minutes. The reactions of phenylacetylene with benzyl azide and phenyl azide substrates led to the corresponding 1,2,3-triazoles in high yields (Table 1, entries 4, 5). Ethyl 2-azidoacetate with electron-withdrawing group gave the cycloaddition product in shorter time than benzyl azide and phenyl azide [10]. The copper(I) complex displayed high activity in the reaction of ethyl 2-azidoacetate with 1-hexyne (Table 1, entry 3). This reaction is slower than that of ethyl 2-azidoacetate with phenyl azide because of using electron rich azide [13].

#### 4. Conclusion

In conclusion, we synthesized a cationic NHC copper(I) complex containing benzimidazol-2-ylidene. The structure of the compound was determined by <sup>1</sup>H NMR, <sup>13</sup>C NMR, <sup>19</sup>F NMR, elemental analysis and ESI/TOF mass spectrometry. Preliminary catalytic studies revealed that the copper(I) complex gave 1,2,3-triazoles in good yields at room temperature under neat conditions.

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#### Author's Contribution

**Deniz Demir Atlı:** Performed the experiment, interpreted to the results, drafted and wrote the manuscript.

**Şebnem E. Sözerli:** Supervised the experiment's progress, result interpretation.

#### Ethics

There are no ethical issues after the publication of this manuscript.

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