Recyclable ruthenium(II) complex supported on magnetic nanoparticles: A regioselective catalyst for alkyne azide cycloaddition

Dong Wang, Lionel Salmon, Jaime Ruiz and Didier Astruc*

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1. **General remarks:**

All reactions and manipulations were performed in a nitrogen-filled glove-box or under nitrogen using standard Schlenk techniques, unless otherwise noted. Tetrahydrofuran was freshly distilled from sodium/benzophenone. Toluene was distilled from sodium. All commercially available reagents were used as received, unless indicated otherwise. Flash column chromatography was performed using silica gel (300–400 mesh). $^1$H NMR spectra were recorded with 300 MHz spectrometer, and $^{13}$C NMR spectra were recorded at 75 with 300 MHz spectrometer. Elemental analyses were performed by the Center of Microanalyses of the CNRS at Lyon Villeurbanne, France.

2. **Experimental section**

**Synthesis of compound 5:**
The freshly prepared (Cp*RuCl$_2$)$_2$ (46 mg, 0.15 mmol) was placed into a 100 mL flask and fitted with a reflux condenser. The flask was purged with nitrogen and 50 mL of absolute ethanol was added. 4 (434 mg, 0.36 mmol) dissolved in 5 mL of THF were added under nitrogen. The mixture was refluxed for 60 h and allowed to cool to room temperature. Then the solvent was removed under vacuum, the obtained solid was washed repeatedly with cold pentane and diethyl ether to afford 326 mg 80% of 5 as orange microcrystals. $^1$H NMR (300 MHz, CDCl$_3$): δ H 7.41–8.06 (m, 28H), 6.74 (bs, 2H), 3.61 (s, 18H), 2.74–2.92 (m, 4H), 1.58–1.82 (m, 4H), 1.13 (s, 15H), 0.78 (t, $J$ = 6.9 Hz, 4H). MS (MALDI-TOF; m/z), calcd. for C$_{60}$H$_{75}$ClN$_2$O$_8$P$_2$RuSi$_2$: 1206.3, found: MNa$^+$ 1228.3. Anal. calcd for C$_{60}$H$_{75}$ClN$_2$O$_8$P$_2$RuSi$_2$: C 59.71, H 6.26, N 2.32, found (%) C 59.95, H 6.49, N 2.03.

**Synthesis of ruthenium(II) complex supported on magnetic nanoparticles (Cp*Ru/SiO$_2$/$\gamma$-Fe$_2$O$_3$) 6:**
0.16 g of 5 dissolved in 5 mL of dry CH$_2$Cl$_2$ were added to a suspension of 0.3 g of magnetic nanoparticles SiO$_2$/$\gamma$-Fe$_2$O$_3$ 2 in 30 mL of dry toluene. The mixture was then stirred at 90°C under an atmosphere of nitrogen overnight. The dark brown solid material obtained was magnetically separated, washed repeatedly with toluene, CH$_2$Cl$_2$ and THF to remove any unanchored species and then dried under vacuum. The obtained catalyst was kept under an atmosphere of nitrogen for further catalytic application.

**General procedures for magnetic catalyst 6 - catalyzed cycloaddition of alkynes and organic azides to 1,5-disubstituted 1,2,3-trizoles:**
A dried Schlenk tube equipped with a magnetic stirring bar was charged under a nitrogen atmosphere with alkyne (0.5 mmol), organic azide (0.5 mmol), catalyst 6 (2 mol%, 63 mg), and 2 mL of dried THF. The mixture was heated at 65°C for 3 h. After cooling to room temperature, the mixture was diluted with ethyl acetate. The catalyst was collected by the usage of a lab magnet and then washed with ethyl acetate (3 x 5 mL) and CH$_2$Cl$_2$ (3 x 5 mL) and then dried at room temperature under vacuum. During above-mentioned treatment for the reaction, the catalyst was always kept under a nitrogen atmosphere. The combined organic phase was dried over Na$_2$SO$_4$
and filtered. The filtrate was removed under reduced pressure to get the crude product, which was further purified by silica gel chromatography (petroleum ether/ethyl acetate as eluent) to yield corresponding triazole. And the recovered catalyst was used for the next reaction cycle.

**Optimization of catalyst loading**

A dried Schlenk tube equipped with a magnetic stirring bar was charged under a nitrogen atmosphere with phenylacetylene (0.5 mmol), benzyl azide (0.5 mmol), catalyst 6 (x mol%), and 2 mL of dried THF. The mixture was heated at 65°C. After cooling to room temperature, the mixture was diluted with ethyl acetate. The catalyst was collected using a lab magnet, washed with ethyl acetate (3 x 5 mL) and CH$_2$Cl$_2$ (3 x 5 mL) and dried at room temperature under vacuum. The combined organic phase was dried over Na$_2$SO$_4$ and filtered. The filtrate was removed under reduced pressure, which produces the crude product that was further purified by silica gel chromatography (petroleum ether/ethyl acetate as eluent), yielding the corresponding triazole.

**Table S1**  Optimization of catalyst loading

<table>
<thead>
<tr>
<th>Cat. (x mol%)</th>
<th>Time</th>
<th>Yield</th>
<th>Selectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 mol%</td>
<td>3 h</td>
<td>91%</td>
<td>&gt;99.9%</td>
</tr>
<tr>
<td>1 mol%</td>
<td>3 h</td>
<td>81%</td>
<td>&gt;99.9%</td>
</tr>
<tr>
<td>1 mol%</td>
<td>12 h</td>
<td>87%</td>
<td>99.1%</td>
</tr>
<tr>
<td>0.5 mol%</td>
<td>3 h</td>
<td>54%</td>
<td>98.9%</td>
</tr>
<tr>
<td>0.5 mol%</td>
<td>12 h</td>
<td>74%</td>
<td>98.3%</td>
</tr>
</tbody>
</table>

**Large-scale synthesis of 7a**

A dried Schlenk tube equipped with a magnetic stir bar was charged under a nitrogen atmosphere with phenylacetylene (10 mmol), benzyl azide (10 mmol), catalyst 6 (2 mol%), and 40 mL of dried THF. The mixture was heated at 65°C in 24 h. After cooling to room temperature, the mixture was diluted with ethyl acetate. The catalyst was collected by the usage of a lab magnet, washed with ethyl acetate (3 x 30 mL) and CH$_2$Cl$_2$ (3 x 30 mL) and dried at room temperature under vacuum. The combined organic phase was dried over Na$_2$SO$_4$ and filtered. The filtrate was removed under reduced pressure, which produces the crude product that was further purified by silica gel chromatography (petroleum ether/ethyl acetate as eluent) to produce the corresponding triazole. Then, the recovered catalyst was used again for the second reaction cycle (Scheme S1).

**Scheme S1**  Cycloaddition reaction between phenylacetylene and benzyl azide in 10-mmol scale.
3. Spectral data of the compounds:

1-Benzyl-5-phenyl-1H-[1,2,3]triazole \(^1\): 7a was isolated as a white solid. \(^1\)H NMR (300 MHz, CDCl\(_3\)): \(\delta_H\) 7.77 (s, 1H), 7.41-7.48 (m, 3H), 7.27-7.34 (m, 5H), 7.09-7.13 (m, 2H), 5.58 (s, 2H). \(^13\)C NMR (75 MHz, CDCl\(_3\)): \(\delta_C\) 138.17, 135.59, 133.22, 129.89, 129.55, 128.99, 128.84, 128.13, 127.14, 126.87, 51.77.

4-(3-Benzyl-3H-[1,2,3]triazol-4-yl)-benzaldehyde \(^1\): 7b was isolated as a white solid. \(^1\)H NMR (300 MHz, CDCl\(_3\)): \(\delta_H\) 10.08 (s, 1H), 7.93-7.97 (m, 2H), 7.84 (s, 1H), 7.45-7.48 (m, 2H), 7.29-7.33 (m, 3H), 7.07-7.12 (m, 2H), 5.62 (s, 2H). \(^13\)C NMR (75 MHz, CDCl\(_3\)): \(\delta_C\) 191.30, 136.99, 136.70, 135.11, 133.87, 132.76, 130.12, 129.45, 129.01, 128.44, 127.06, 52.27.

1-Benzyl-5-(4-bromo-phenyl)-1H-[1,2,3]triazole: 7c was isolated as a pale yellow solid. \(^1\)H NMR (300 MHz, CDCl\(_3\)): \(\delta_H\) 7.76 (s, 1H), 7.57 (d, \(J = 8.7\) Hz, 2H), 7.30-7.34 (m, 3H), 7.08-7.15 (m, 4H), 5.56 (s, 2H). \(^13\)C NMR (75 MHz, CDCl\(_3\)): \(\delta_C\) 137.14, 135.32, 133.51, 132.24, 130.45, 128.97, 128.34, 127.08, 125.86, 124.04, 51.97. IR (cm\(^{-1}\)): 3439, 3064, 1603, 1550, 1481, 1242, 1210, 1113, 1074, 1008, 974, 824, 728, 584. TOF HRMS: calcd. for C\(_{15}\)H\(_{12}\)N\(_3\)NaBr \([M+Na]^+\): 336.0106, found: 336.0109.

1-Benzyl-5-(4-nitro-phenyl)-1H-[1,2,3]triazole: 7d was isolated as a yellow solid. \(^1\)H NMR (300 MHz, CDCl\(_3\)): \(\delta_H\) 8.26-8.30 (m, 2H), 7.86 (s, 1H), 7.45-7.50 (m, 2H), 7.31-7.34 (m, 3H), 7.06-7.10 (m, 2H), 5.63 (s, 2H). \(^13\)C NMR (75 MHz, CDCl\(_3\)): \(\delta_C\) 148.28, 136.09, 134.90, 134.14, 133.37, 129.76, 129.11, 128.57, 126.99, 124.16, 52.39. IR (cm\(^{-1}\)): 3439, 3103, 1957, 1603, 1518, 1454, 1353, 1108, 974, 854, 729, 584. TOF HRMS: calcd. for C\(_{15}\)H\(_{13}\)N\(_4\)O\(_2\) \([M]^+\): 281.1033, found: 281.1043.
1-Benzyl-5-(4-methoxy-phenyl)-1H-[1,2,3]triazole²: 7e was isolated as a white solid. ¹H NMR (300 MHz, CDCl₃): δH 7.58 (s, 1H), 7.15-7.20 (m, 3H), 7.05-7.09 (m, 2H), 6.97-7.00 (m, 2H), 6.81-6.84 (m, 2H), 5.42 (s, 2H), 3.72 (s, 3H). ¹³C NMR (75 MHz, CDCl₃): δC 160.52, 138.02, 135.72, 133.05, 130.24, 128.84, 128.11, 127.12, 118.96, 114.44, 55.41, 51.68.

2-(3-Benzyl-3H-[1,2,3]triazol-4-yl)-pyridine³: 7f was isolated as a white solid. ¹H NMR (300 MHz, CDCl₃): δH 8.72 (d, J = 4.8 Hz, 1H), 8.04 (s, 1H), 7.73-7.79 (m, 1H), 7.57 (d, J = 7.8 Hz, 1H), 7.26-7.32 (m, 6H), 6.20 (s, 2H). ¹³C NMR (75 MHz, CDCl₃): δC 149.55, 147.02, 137.08, 136.16, 135.65, 133.68, 128.52, 127.89, 123.37, 123.30, 122.82, 53.13.

3-(3-Benzyl-3H-[1,2,3]triazol-4-yl)-pyridine³: 7g was isolated as a brown solid. ¹H NMR (300 MHz, CDCl₃): δH 8.66 (s, 1H), 8.52 (s, 1H), 7.79 (d, J = 2.1 Hz, 1H), 7.51-7.55 (m, 1H), 7.24-7.36 (m, 4H), 7.03-7.06 (m, 2H), 5.57 (s, 2H). ¹³C NMR (75 MHz, CDCl₃): δC 150.60, 149.28, 136.18, 135.02, 134.88, 133.96, 129.01, 128.44, 127.04, 123.60, 123.35, 52.18.

1-Benzyl-5-butyl-1H-[1,2,3]triazole¹: 7h was isolated as a pale yellow solid. ¹H NMR (300 MHz, CDCl₃): δH 7.46 (s, 1H), 7.27-7.34 (m, 3H), 7.12-7.15 (m, 2H), 5.48 (s, 2H), 2.48 (t, J = 7.8 Hz, 2H), 1.43-1.53 (m, 2H), 1.17-1.35 (m, 2H), 0.84 (t, J = 7.2 Hz, 3H). ¹³C NMR (75 MHz, CDCl₃): δC 137.48, 135.11, 132.51, 128.92, 128.23, 127.08, 51.58, 29.88, 22.81, 22.14, 13.61.

1-Benzyl-5-ferrocenyl-1H-[1,2,3]triazole⁴: 7i was isolated as a golden yellow solid. ¹H NMR (300 MHz, CDCl₃): δH 7.78 (s, 1H), 7.30-7.38 (m, 3H), 7.11 (d, J = 7.2 Hz, 2H), 5.67 (s, 2H), 4.37 (s, 2H), 4.32 (s, 2H), 4.06 (s, 5H). ¹³C NMR (75 MHz, CDCl₃): δC 136.55, 135.86, 132.93, 128.97, 128.08, 126.57, 70.59, 69.75, 69.61, 68.37, 51.72.
1-(4-Bromo-benzyl)-5-phenyl-1H-[1,2,3]triazole\textsuperscript{5} : 7\textit{j} was isolated as a pale yellow solid. \textsuperscript{1}H NMR (300 MHz, CDCl\textsubscript{3}): \(\delta_H\) 7.76 (s, 1H), 7.41-7.50 (m, 5H), 7.25-7.30 (m, 2H), 6.96-7.00 (m, 2H), 5.52 (s, 2H). \textsuperscript{13}C NMR (75 MHz, CDCl\textsubscript{3}): \(\delta_C\) 138.12, 134.47, 133.29, 131.91, 129.65, 129.06, 128.93, 128.79, 126.65, 122.22, 51.13.

1-Hexyl-5-phenyl-1H-[1,2,3]triazole \textsuperscript{6} : 7\textit{k} was isolated as a pale yellow solid. \textsuperscript{1}H NMR (300 MHz, CDCl\textsubscript{3}): \(\delta_H\) 7.65 (s, 1H), 7.46-7.51 (m, 3H), 7.35-7.38 (m, 2H), 4.32 (t, \(J = 7.4\) Hz, 2H), 1.75-1.82 (m, 2H), 1.19-1.26 (m, 6H), 0.80 (t, \(J = 6.2\) Hz, 3H). \textsuperscript{13}C NMR (75 MHz, CDCl\textsubscript{3}): \(\delta_C\) 137.67, 132.95, 129.40, 129.07, 128.71, 127.31, 48.28, 31.01, 30.02, 26.06, 22.33, 13.88.

1-Octyl-5-phenyl-1H-[1,2,3]triazole \textsuperscript{7} : 7\textit{l} was isolated as a pale yellow solid. \textsuperscript{1}H NMR (300 MHz, CDCl\textsubscript{3}): \(\delta_H\) 7.65 (s, 1H), 7.46-7.48 (m, 3H), 7.35-7.38 (m, 2H), 4.32 (t, \(J = 7.2\) Hz, 2H), 1.75-1.85 (m, 2H), 1.17-1.24 (m, 10H), 0.83 (t, \(J = 6.6\) Hz, 3H). \textsuperscript{13}C NMR (100 MHz, CDCl\textsubscript{3}): \(\delta_C\) 137.86, 133.15, 129.58, 129.26, 128.91, 127.52, 48.48, 31.85, 30.25, 29.15, 29.02, 26.58, 22.76, 14.24.

1-(4-Methoxy-phenyl)-5-phenyl-1H-[1,2,3]triazole \textsuperscript{8} : 7\textit{m} was isolated as a pale yellow solid. \textsuperscript{1}H NMR (300 MHz, CDCl\textsubscript{3}): \(\delta_H\) 7.89 (s, 1H), 7.25-7.40 (m, 7H), 6.95-6.98 (m, 2H), 3.88 (s, 3H). \textsuperscript{13}C NMR (100 MHz, CDCl\textsubscript{3}): \(\delta_C\) 160.10, 137.73, 133.22, 129.64, 128.86, 128.57, 126.91, 126.64, 114.52, 55.60.

1-Benzyl-4,5-diphenyl-1H-[1,2,3]triazole \textsuperscript{1} : 8 was isolated as a white solid. \textsuperscript{1}H NMR (300 MHz, CDCl\textsubscript{3}): \(\delta_H\) 7.46-7.50 (m, 2H), 7.32-7.40 (m, 3H), 7.14-7.21 (m,
7H), 7.05-7.08 (m, 2H), 6.93-6.96 (m, 2H), 5.33 (s, 2H). $^{13}$C NMR (100 MHz, CDCl$_3$):

$\delta$C 144.59, 135.47, 134.00, 131.04, 130.18, 129.79, 129.27, 128.78, 128.54, 128.23, 127.94, 127.79, 127.59, 126.81, 52.11.

4. References

5. NMR spectra of the products

7a:
7d:
7e:
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7g:

[Diagram of a chemical structure and NMR spectrum]

514
7i:
6. IR spectrums of 7c and 7d

7c:

7d: