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Allene Cross-Metathesis: Synthesis of 1,3-Disubstituted Allenes

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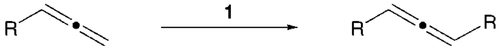
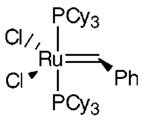
ABSTRACT



Grubbs catalyst, $Cl_2(Cy_3P)_2Ru{=}CHPh$, was found to catalyze the cross-metathesis of monosubstituted allenes to 1,3-disubstituted allenes in varying yields.

The olefin metathesis reaction,[1] catalyzed by well-defined transition metal alkylidene complexes **1**[2] and **2**,[3] has been known for more than a decade now and has been extensively explored. These metathesis catalysts are routinely employed for the generation of carbon−carbon double bonds, either by cross-metathesis of two acyclic alkenes or by ring-closing metathesis (RCM) of a diene.[4] More recently, the combination of alkene and alkyne metathesis has provided a very powerful technique for generating 1,3-dienes (enyne metathesis).[5]

In our efforts to expand the scope of metathesis chemistry mediated by carbenes **1** and **2**, we now wish to report the action of Grubbs catalyst **1** on monosubstituted allenes. To the best of our knowledge, exposure of the allene moiety to metathesis catalyst **1** or **2** has not been previously reported.



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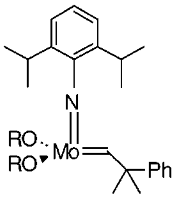
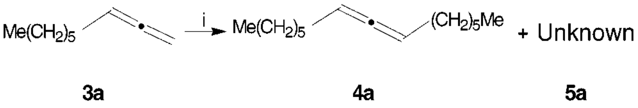


2 R = $C(CH_3)(CF_3)_2$

Prior to carrying out this reaction, and based upon the known mode of action of ruthenium catalyst **1**,[6] we postulated a number of outcomes. It was expected that the product mixture might consist of variously substituted cumulenes, a 1,3-disubstituted allene (with elimination of allene gas), or a 1,2-disubstituted olefin.

To this end, allene **3a**[7] was allowed to react with Grubbs catalyst **1** (Scheme 1), giving 1,3-disubstituted allene **4a** as the major product, together with a small amount of unidentified organic material **5a**.

Scheme 1



Reagents: (i) **1** (5 mol %), CH_2Cl_2, 20 °C, 20 h, 72% (**4a**).

Encouraged by this result, other monosubstituted allenes were prepared[7,8] and allowed to react with Grubbs carbene **1** (Table 1).[9] In many cases we were surprised to find that

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[1] For recent reviews, see: Grubbs, R. H.; Chang, S. *Tetrahedron* **1998**, *54*, 4413. Armstrong, S. K. *J. Chem. Soc., Perkin Trans. 1* **1998**, 371.

[2] Schwab, P.; Marcia, M. B.; Ziller, J. W.; Grubbs, R. H. *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 2039

[3] Schrock, R. R.; Murdzek, J. S.; Bazan, G. C.; Robbins, J.; DiMare, M.; O'Regan, M. *J. Am. Chem. Soc.* **1990**, *112*, 3875.

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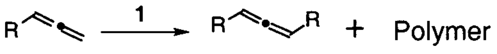
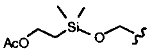
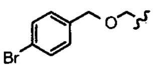
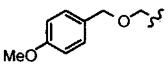
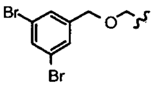
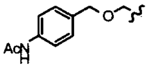
Table 1

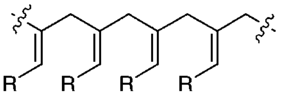


3a-p **4a-p** **5a-p**

entry[a]	R	time (h)	conversion[b] (%) 4	5
a	Me(CH$_2$)$_5$-	20	85 (70)[c]	10
b	THPO(CH$_2$)$_3$-	15	30 (20)[c]	65
c	Cy(CH$_2$)$_2$-	20	35	65
d	TBSOCH$_2$-	12	10	90
e	PhCH$_2$OCH$_2$-	20	50 (20)[c]	50
f		24	15	85
g		20	25	75
h		20	20	80
i		15	40	60
j		60	100 (75)[c]	0
k	Phenyl-	20	0	100
l	*o*-Tolyl-	48[d]	0	0
m	*m*-Tolyl-	15	0	95
n	*p*-Tolyl-	24	0	95
o	*p*-Fluorophenyl-	48[e]	0	0
p	*p*-Chlorophenyl-	48[e]	0	0

[a] All reactions conducted with 5 mol % of **1** in CH$_2$Cl$_2$ at 20 °C. [b] On the basis of ^{1}H NMR data. [c] Numbers in parentheses represents isolated yield (for entry e, polymer **4e** constitutes approximately 10% of isolated yield). [d] Starting material consumed. [e] Starting material recovered.

the 1,3-disubstituted product was in fact the minor component, along with a second major product of unknown identity. It was suspected that the unknown compound might be polymeric in nature as indicated by the relatively broad nature of the signals in the ^{1}H NMR spectra.[10] Following isolation by column chromatography, the unknown product was analyzed by gel permeation chromatography (GPC) which clearly showed that the unknown material was polymeric, with a value for M_W ranging between 3600 and 5700 (PDI 20). The structure of polymer **5** was supported by comparison of its IR and ^{1}H NMR data to that reported in the literature, where R = Me.[11]



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That polymer **5** was not formed from disubstituted allene **4** was demonstrated by re-exposure of isolated allene **4** to Grubbs carbene **1**. Polymer **5** was also found to be unaffected by reexposure to catalyst **1**.

The possibility that minor ruthenium catalyst decomposition products were responsible for polymerization was eliminated by allowing carbene **1** to stand in nondegassed dichloromethane for 1 h, followed by addition of allene **3**. No polymerization (nor allene metathesis) was observed.

The reactions conducted for entries a–i (Table 1) led to a mixture of disubstituted allene **4a–i** and polymer **5a–i**. In contrast, 4-(acetamido)benzyl allenyl ether (**3j**) gave only disubstituted allene **4j** (entry j).

To probe further the steric and electronic effects of the allene substituent (R), a series of phenylallenes were prepared and treated with ruthenium carbene **1** (entries k–p). This revealed that phenyl-, *m*-tolyl-, and *p*-tolylallene undergo almost complete conversion to the polymer (entries k, m, and n). For entry l, *o*-tolylallene **3l** was completely consumed in the reaction but no identifiable product could be detected. Electron-deficient phenylallenes **3o** and **3p** did not react to give the corresponding disubstituted allene nor polymer.

Alternative metathesis catalysts **2** and **7–9** were examined in their reaction with monosubstituted allenes **3g** and **3j**. When 5 mol % of molybdenum catalyst **2** was employed,

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(4) For our recent contributions, see: Ahmed, M.; Barrett, A. G. M.; Beall, J. C.; Braddock, D. C.; Flack, K.; Gibson, V. C.; Procopiou. P. A.; Salter, M. M. *Tetrahedron* **1999**, *55*, 3219. Barrett, A. G. M.; Baugh, S. P. D.; Braddock, D. C.; Flack, K.; Gibson, V. C.; Giles; M. R.; Marshall, E. L.; Procopiou, P. A.; White, A. J. P.; Williams, D. J. *J. Org. Chem.* **1998**, *63*, 7893. Ahmed, M.; Barrett, A. G. M.; Braddock, D. C.; Cramp, S. M.; Procopiou, P. A. *Tetrahedron Lett.* **1999**, *40*, 8657.

(5) Barrett, A. G. M.; Baugh, S. P. D.; Braddock, D, C.; Flack, K.; Gibson, V. C.; Procopiou, P. A. *Chem. Commun.* **1997**, 1375. Kinoshita, A.; Mori, M. *Synlett* **1994**, 1020. Clarke, J. S.; Trevitt, G. P.; Boyall, D.; Stammen. B. *Chem. Commun.* **1998**, 2629.

(6) Dias, E. L.; Nguyen, S. T.; Grubbs, R. H. *J. Am. Chem. Soc.* **1997**, *119*, 3887.

(7) Skattebol, L. *J. Org. Chem.* **1966**, *31*, 2789.

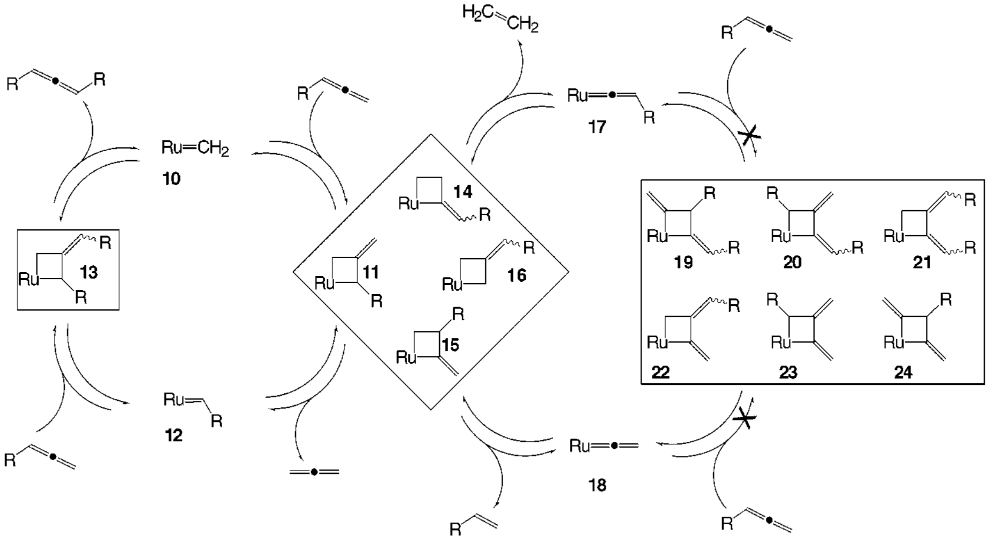
(8) Kimura, M.; Tanaka, S.; Tamaru, Y. *Bull. Chem. Soc. Jpn.* **1995**, *68*, 1689. Endo, T.; Takagi, K.; Tomita, I. *Tetrahedron* **1997**, *53*, 15187.

(9) In a typical procedure: ruthenium catalyst **1** (5 mol %) was added to monosubstituted allene **3b** (50 mg) in CH$_2$Cl$_2$ (typical concentration 0.1 M) and the resulting mixture stirred at ambient temperature for 15 h. The solvent was evaporated and chromatography (pentane) employed to provide the disubstituted allene **4b** (10 mg, 20%): ^{1}H (300 MHz) 5.13 (quint, 2H, J = 4.8 Hz, C*H*=C=C*H*), 4.58 (t, 2H, J = 4.0 Hz), 3.81 (m, 4H), 3.45 (m, 4H), 2.07 (m, 4H), 1.83 (m, 2H), 1.71 (m, 6H), 1.52 (m, 8H); ^{13}C (75 MHz) 203.9 (CH=*C*=CH), 98.8, 90.9 (*C*H=C=*C*H), 66.9, 62.2, 30.7, 29.2, 25.6, 25.5, 19.6.

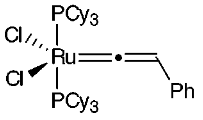
(10) For **5d**: ^{1}H (400 MHz) δ 5.40 (br t, 1H, J = 6 Hz), 4.10 (br d, 2H, J = 6 Hz), 2.60 (br s, 2H), 0.85 (s, 9H), 0.00 (s, 6H); ^{13}C (100 MHz) δ 134, 128, 60, 38, 26, 18.

(11) Otsuka, S.; Mori, K.; Suminoe, T.; Imaizumi, F. *Eur. Polym. J.* **1967**, *3*, 73. Ghalamkar-Moazzam, M.; Jacobs, T. L. *J. Polym. Sci. Polym. Chem. Ed.* **1978**, *16*, 615.

Scheme 2



no reaction was observed, even after 48 h. There was no apparent catalyst decomposition; the color of the reaction mixture remained deep orange. Treating the two monosubstituted allenes with ruthenium vinylidene **7**[12] (5 mol %) led to essentially the same product distribution as obtained using Grubbs carbene **1**, over a similar time period. In reactions employing allenylidene complex **8**[13](5 mol %) and ruthenium carbene **9**[14](5 mol %, 45 °C), the rate of reaction was found to be very slow, but the reaction mixture still consisted of polymer and disubstituted allene (as observed with Grubbs catalyst **1**).



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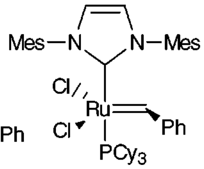

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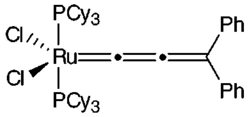

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A mechanistic pathway leading to the formation of the observed allene is proposed in Scheme 2. Reaction of ruthenium carbene **10** and the monosubstituted allene could provide three productive metallocyclobutane derivatives, **11**, **14**, and **15** (adduct **16** is nonproductive since it can only fragment to give the starting allene and catalyst **10**). Collapse of adduct **11**, with loss of allene gas, would yield ruthenium alkylidene **12** which could give metallocycle **13**, through interaction with another molecule of monosubstituted allene. The catalytic cycle is completed with metallocycle **13** collapsing to give the observed 1,3-disubstituted allene together with ruthenium carbene **10**. Metallocycles **14** and **15** can conceivably give productive metathesis adducts via **19**−**24**; however, these species have a common motif in that they are all bis(*exo*-methylene)metallocyclobutanes. In contrast, adduct **12** can react via a mono(*exo*-methylene)-metallocyclobutane (**13**) to give an allene and carbene **10**. Hence, we feel that due to the greater steric demands of other adducts, the catalytic cycle proceeds via the relatively less energetically demanding metallocycles **11** and **13** to provide the reported allene. At this stage it is not clear how the polymeric material is generated.

In conclusion, we have reported the first interaction of ruthenium carbene **1** with monosubstituted allenes. The products of the reaction are either 1,3-disubstituted allene or polyallenes. Further applications of ruthenium carbene **1** to allenes will be reported in due course.

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[12] Katayama, H.; Ozawa, F. *Organometallics* **1998**, *17*, 5190.

[13] Harlow, K. J.; Hill, A. F.; Wilton-Ely, J. D. E. T. *J. Chem. Soc., Dalton Trans.* **1999**, 285.

[14] Huang, J.; Stevens, E. D.; Nolan, S. P.; Peterson, J. L. *J. Am. Chem. Soc.* **1999**, *121*, 2674. Scholl, M.; Trnka, T. M.; Morgan, J. P.; Grubbs, R. H. *Tetrahedron Lett.* **1999**, *40*, 2247.