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# An Exceptionally Simple and Efficient Method for the Preparation of a Wide Variety of Fulvenes

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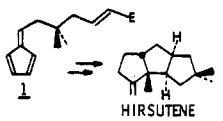
A simple high yield method for the preparation of a wide range of structurally diverse fulvenes is described. Pyrrolidine proves to be a very effective reagent to promote fulvene formation between cyclopentadiene and a host of carbonyl compounds including simple ketones, 4-tetrahydrothiopyranone, 4-tetrahydropyranone, aldehydes bearing acidic $\alpha$ hydrogens, sterically encumbered aldehydes, as well as optically pure tetrahydrofuranyl aldehydes. With the exception of sterically hindered ketones such as 2,6-dimethylcyclohexanone, the reaction proceeds in acceptable to excellent yields. The effect of variation of temperature, solvent, and concentration upon the course of the reaction was examined qualitatively. Methanol proved to be the solvent of choice. Deuterium–hydrogen exchange experiments (between MeOD, starting materials, and product) were conducted and it was found that deuterium can be encorporated both before and after fulvene formation. Epimerization of the optically pure fulvene 4 occurred to the extent of 12%.

## Introduction

Fulvenes are both interesting and synthetically useful compounds as is evidenced by the fact that they have served as the subject of many investigations for more than 80 years.[1] Our interest stems from their usefulness as synthetic precursors to naturally occurring compounds. For example, fulvenes 1 (E = $CO_2CH_3$) and 2 have served as key intermediates in total syntheses of *d,l*-hirsutene and *d,l*-$\Delta^{9,12}$-capnellene, respectively.[2a,3]

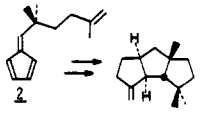
## Results and Discussion

In 1976, Büchi and co-workers reported the preparation of 6-(4-oxopentyl) fulvene by using a modification of a procedure originally reported by Freiesleben.[4] This modification proved to be very useful to us for the preparation of a number of fulvenes (e.g., 1 in 91% yield).




1

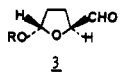
HIRSUTENE



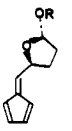

2

CAPNELLENE

However, for sterically hindered aldehydes such as isobutyraldehyde, the corresponding fulvene could be obtained in no greater than 40% yield. Furthermore, fulvene 2 could not be prepared,[5] and the valuable chiral aldehyde 3 (R = $SiMe_2$-*t*-Bu) was found to be particularly unreactive; the fulvene derived from compound 3, namely 4, is




3




4

of considerable importance to us in conjunction with another project.[6] Since, with the exception of a few general methods for the preparation of fulvenes,[7] most of the recorded procedures are either specific for the preparation of a particular type of fulvene or afford only poor to moderate yields,[8] it was important to us to devise a ver-

† Alfred P. Sloan Foundation Fellow, 1980–1984.

(1) For reviews, see: (a) Yates, P. *Adv. Alicyclic Chem.* **1968**, *2*, 59. (b) Bergmann, E. D. *Chem. Rev.* **1968**, *68*, 41.

(2) (a) Little, R. D.; Muller, G. W. *J. Am. Chem. Soc.* **1981**, *103*, 2744. (b) Little, R. D.; Moeller, K. D. *J. Org. Chem.* **1983**, *48*, 4487. (c) Little, R. D.; Higby, R. G.; Moeller, K. D. *J. Org. Chem.* **1983**, *48*, 3139. (d) Little, R. D.; Muller, G. W.; Venegas, M. G.; Carroll, G. L.; Bukhari, A.; Patton, L.; Stone, K. *Tetrahedron, Symposia in Print* **1981**, *37*, 4371.

(3) Little, R. D.; Carroll, G. L.; Petersen, J. L. *J. Am. Chem. Soc.* **1983**, *105*, 928.

(4) Buchi, G.; Berthot, D.; Decorzant, R.; Greider, A.; Hauser, A. *J. Org. Chem.* **1976**, *41*, 3208. Freiesleben, W. Ger. Pat. 1146050, 1963; *Chem. Abstr.* **1963**, *59*, 9914. Freiesleben, W. *Angew. Chem.* **1963**, *72*, 576.

(5) Fortunately, however, due to the absence of $\alpha$ hydrogens, lithium cyclopentadienide (from *n*-BuLi) in THF could be employed in this case, and 2 was isolated in 70% yield. See ref 3.

(6) Little, R. D.; Stone, K. J. *J. Am. Chem. Soc.* **1983**, *105*, 6976.

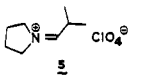
(7) (a) Kyburg, R.; Schaltegger, H.; Neuenschwander, M. *Helv. Chim. Acta* **1971**, *54*, 1037. (b) Neuenschwander, M.; Iseli, R. *Ibid.* **1977**, *60*, 1061.

0022-3263/84/1949-1849$01.50/0 

satile and generally applicable method for the preparation of these and other fulvenes. In this manuscript, we report a convenient procedure for the preparation of 6-substituted and 6,6-disubstituted fulvenes which often proceeds quickly, is applicable to the preparation of structurally diverse fulvenes, and is most often quite efficient.

**Pyrrolidine. An Effective Reagent for the Promotion of Fulvene Formation.** The idea of preforming an iminium ion to serve as an acceptor toward cyclopentadienide appeared to constitute an attractive starting point for our studies. Literature precedent from the work of Leonard and Paukstelis indicated that pyrrolidinium perchlorate reacts with 2 equiv of an aldehyde or a ketone to afford a stable imminium perchlorate, even when an enamine could have been formed.[9] The condensation of cyclopentadienide with these salts might provide a viable method for fulvene formation, and an especially attractive one if no epimerization occurred at the carbon $\alpha$ to the carbonyl, thereby allowing the preparation of $\alpha$ chiral fulvenes from the corresponding chiral aldehydes without racemization.

To test this idea, attempts were made to prepare 6-isopropylfulvene from *N*-isobutylidene pyrrolidinium perchlorate **5**.[10] When a solution of this salt and 2.5 equiv



**5**

of cyclopentadiene in methanol (2 mL/mmol of **5**) was prepared, no color change indicative of fulvene formation was observed. However, the solution turned bright yellow almost *immediately* after the addition of 1.5 equiv of diethylamine. In two control experiments utilizing isobutyraldehyde instead of **5**, the solution turned *pale* yellow in about 4 min after adding diethylamine—significantly slower than with the preformed iminium ion. When pyrrolidine was employed in a similar control experiment, however, a *bright* yellow solution formed in less than 2 min.

The apparent implication of these experiments was that pyrrolidine was responsible for the enhanced rate of fulvene formation. Credibility was added to this assumption by isolating a 98% yield of spectroscopically pure 6-isopropylfulvene after only 15 min using pyrrolidine, in stark contrast with the 40% yield obtained using diethylamine after 2.5 h. Furthermore, fulvene **2** could be prepared in 59% (not optimized) from the sterically hindered neopentyl aldehyde, 2,2,5-trimethyl-5-hexenal. While this reaction required 17 h to complete and is therefore significantly slower than the previous example, the result is again in dramatic contrast with the analogous diethlamine-catalyzed reaction which provided *none* of the fulvene **2**, even after 24 h!

This striking difference between pyrrolidine and diethylamine cannot be attributed to a difference in basicity since both amines have essentially the same base strength [$pK_a$(pyrrolidine–$H^+$) = 11.27 while $pK_a$(diethylamine–$H^+$) = 11.04].[11] Pyrrolidine, however, with it's two alkyl groups "tied back", probably reacts significantly faster than diethylamine. This steric factor could manifest itself in several of the steps of the overall sequence. For example, a faster rate of nucleophilic attack of the amine on the carbonyl carbon could result in a higher steady-state concentration of the iminium ion, whereas a faster rate of proton abstraction with the sterically less demanding pyrrolidine might increase the rate of the fulvene forming step. This suggestion would be in accord with the finding of Bunton and Watts who determined that deprotonations with sterically hindered amines cause deviations in the linearity of Brønstead plots, reflecting steric hindrance to proton transfer.[12] Whatever the precise role, the experimental observations imply that the amine is involved in the rate-determining step of the reaction sequence.

**Effects of Variation of Reaction Conditions.** We have qualitatively examined the role of temperature, solvent, and concentration upon the course of the reaction.

**Temperature.** As anticipated, the rate of reaction was proportional to temperature. For example, the conversion of isobutyraldehyde to 6-isopropylfulvene was complete (GC analysis) in <12 min at a temperature of 20–24 °C, while at 0 °C, GC analysis (cyclohexane internal standard) showed 17%, 40%, 62%, and 73% product after 11, 30, 60 and 105 min, respectively. At −78 °C, no product could be detected after 2 h. Using the sterically hindered 2-methylcyclohexanone, a significantly larger amount of a byproduct was produced when the reaction was conducted at 40 °C instead of room temperature.[13] This reaction mixture also turned dark brown much faster (i.e., 15 min vs. 2 h) than those reactions run at room temperature even though there was no significant rate enhancement, as indicated by loss of starting ketone or formation of product.

**Solvent.** From all indications obtained thus far, methanol is the preferred solvent in which to carry out the fulvene-forming reaction. This solvent greatly enhances the rate of the reaction compared with 2-propanol, THF, or methylene chloride. Reactions run in the absence of solvent proceeded significantly slower than in methanol,[4] in agreement with the findings of Neuenschwander and co-workers.[14]

A series of deuterium incorporation experiments also indicate direct solvent participation in the reaction. For example, hydrogen–deuterium exchange between cyclopentadiene and methanol-O-*d* is quite fast in the presence of pyrrolidine, even in an aprotic solvent such as $CDCl_3$. Furthermore, when 6-(*n*-heptyl)fulvene was prepared from octanal, cyclopentadiene, and diethylamine, the ratio of the vinylic to allylic to aliphatic proton NMR signals de-

(8) (a) Thiele, J. *Chem. Ber.* **1900**, *33*, 666. Thiele, J. *Liebigs Ann. Chem.* **1906**, 348. (b) Thiec, J.; Wiemann, J. *Bull Soc. Chim. Fr.* **1956**, 177; *Ibid.* **1957**, 366; *Ibid.* **1960**, 1066. (c) Kohler, E. P.; Kable, J. *J. Am. Chem. Soc.* **1935**, *57*, 917. (d) Angus, H. J. F.; *Bryce*-Smith, D. *J. Chem. Soc.* **1960**, 1409. (e) Meuche, D.; Neuenschwander, M.; Schaltegger, H.; Schlunegger, H. U. *Helv. Chim. Acta* **1964**, *47*, 1211. Meuche, D. *Ibid.* **1966**, *49*, 1278. (f) Coutot, C. *Ann. Chim. (Paris)* **1915**, *4*, 168. (g) Ziegler, K.; Crossmann, F. *Liebigs Ann. Chem.* **1934**, *511*, 89. (h) Bergmann, E. D.; Cook, J. W. *Prog. Org. Chem.* **1955**, 81. (i) Fenton, D. M.; Hurwitz, M. J. *J. Org. Chem.* **1963**, *28*, 1646. (j) Smith, W. B.; Gonzales, C. *Ibid.* **1963**, *28*, 3541. (k) Mohrbacher, R. J.; Paragamian, V.; Carson, E. L.; Puma, B. M.; Rasmussen, C. R.; Meschina, J. A.; Poos, G. I. *Ibid.* **1966**, *31*, 2149. (l) Grignard, V.; Courtot, C. *CR Hebd. Seances Acad. Sci.* **1914**, *158*, 1763; *Ibid.* **1915**, *160*, 500. (m) Tucker, S. H.; Whalley, M. *J. Chem. Soc.* **1949**, 50. (n) Riemschneider, R.; Horner, E.; Herzel, F. *Monatsh.* **1961**, *92*, 777. (o) McCain, G. H. *J. Org. Chem.* **1958**, *23*, 632; U.S. Pat. 3 051 765, 1962. (p) Sack, H. Fr. Pat. 1 134 170, 1970; *Chem. Abstr.* **1957**, *51*, 12969. (q) Sakai, K.; Kobori, T.; Fujisawa, T. *Tetrahedron Lett.* **1981**, *22*, 115. (r) Alper, H.; Laycock, D. E. *Synthesis* **1980**, 799. (s) Gilman, H.; Gorsich, R. D. *J. Org. Chem.* **1958**, *23*, 550. (t) Saegusa, T.; Ito, Y.; Tomita, S. *J. Am. Chem. Soc.* **1971**, *93*, 5656. (u) Sturm, E.; Hafner, K. *Angew. Chem.* **1964**, *76*, 862. (v) Crane, G.; Boord, C. E.; Henne, A. L. *J. Am. Chem. Soc.* **1945**, *67*, 1237.

(9) Leonard, N. J.; Paukstelis, J. V. *J. Org. Chem.* **1963**, *28*, 3021.

(10) This material was easily prepared by following the procedure presented in ref 9. The low 38% yield (cf. literature value of 92%) was probably due to the use of only 1 equiv of aldehyde.

(11) "Handbook of Tables for Organic Compound Identification", 3rd edition; CRC Press: Cleveland, OH, 1976.

(12) Bunton, C. A.; Carrasco, N.; Davoudzadeh, F.; Watts, W. E. *J. Chem. Soc., Perkin Trans. 2* **1981**, 924.

(13) (a) Presumably, the byproduct is the Diels–Alder adduct of cyclopentadiene and the fulvene. Compare with the observations of Schonholzer, S.; Slongo, M.; Rentsch, C.; Neuenschwander, M. *Makromol. Chem.* **1980**, *181*, 37. (b) Side reactions during fulvene formation from aldehydes using EtONa have also been investigated in detail. See: Neuenschwander, M.; Schadeli, U. *Chimia* **1981**, *35*, 476.

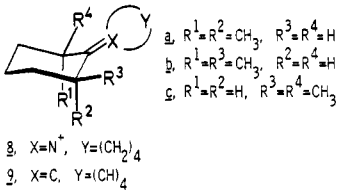
(14) Neuenschwander, M.; Granwehr, B. *Chimia* **1974**, *23*, 59.

creased from 2.6:1:7 to 2.5:1:14 when the solvent was changed from $CH_3OH$ to $CH_3OD$, thereby indicating incorporation of deuterium into both the ring and the aliphatic chain. Finally, when 6-(2′-tetrahydrofurfuryl)-fulvene was prepared from 2-tetrahydrofurfural in the presence of pyrrolidine, the ratio of vinylic to allylic to $-CH_2O-$ proton NMR signals decreased from 5:1:2.5 to 3.5:1:2 upon changing the solvent from $CH_3OH$ to $CH_3OD$. In addition, when this fulvene was redissolved in $CD_3OD$ in the presence of pyrrolidine, the vinyl to $-CH_2O-$ ratio decreased from 3.5:2 to 1:2 after 20 h, thereby indicating that deuterium incorporation into the cyclopentyl ring can occur *both before and after* fulvene formation, even under these mildly basic conditions.[15,16]

**Concentration.** To qualitatively determine the effect of concentration, 2-methylcyclohexanone was used as a model substrate. This ketone is converted into the corresponding fulvene considerably slower than most carbonyl compounds. Under the standard reaction conditions (1 mL MeOH/mmol of substrate, 2.5 equiv of cyclopentadiene, and 1.5 equiv of pyrrolidine at room temperature), $^1H$ NMR analysis showed that ca. 20% of the starting material remained after 22 h. When the amount of cyclopentaidene was increased 10-fold, the rate of the reaction appeared to decrease (TLC analysis). This is perhaps, a consequence of dilution.

The rate of reaction was found to be quite dependent upon the concentration of pyrrolidine. For example, when the amount of pyrrolidine was decreased by a factor of ten, the rate of reaction dropped markedly. By TLC, the reaction did not proceed as far toward completion after 4.5 h as did the reaction under the standard conditions after only 15 min. When the amount of pyrrolidine was increased to 5 equiv, no starting ketone could be detected (TLC) after only 7.5 h. Under these conditions, a 77% yield (after chromatography) of the desired fulvene was obtained.

**Scope and Limitations.** As Table I indicates, the methodology described above is applicable to the preparation of a wide variety of 6-monosubstituted and 6,6-disubstituted fulvenes. It is significant to notice that the yields for the preparation of the fulvenes listed as entries 1–3, 5, 6, 9, and 10 are significnatly higher than any of the values which are reported in the literature for the preparation of the same compounds. A particularly noteworthy example of the utility of the methodology stems from a realization that until as late as 1981, the heterocyclic fulvenes **6** and **7** constituted a new class of fulvenes, and until now, **7** was available in only a 42% yield.[17] Another noteworthy example is entry 11, wherein we have been able to easily prepare the fulvene **2** from a sterically very congested neopentyl aldehyde precursor. Previously, this fulvene was not accessible by using diethylamine, thereby necessitating the use of the more reactive, more basic reagent lithium cyclopentadienide in order to achieve the desired objective.[3] With the sterically encumbered 2,6-dimethylcyclohexanone, it was difficult to accomplish the desired reaction even after prolonged reaction times; thus, even after 48 h at room temperature, no product could be detected. The most apparent reason for this result could be couched solely in terms of an argument which focuses upon steric hindrance toward the addition of a nucleophile to the carbonyl carbon. In addition, however, one must not ignore the fact that the fulvene forming sequence undoubtedly proceeds through a series of equilibria. For this reason, it is important to note that *both* the intermediate imminium ions **8a–c** and the fulvenes **9a–c** are




expected to be thermally unstable due to the *unavoidable* existence of energy raising $A^{1,3}$ and/or 1,3-diaxial interactions.[18] Consequently, and in accord with our results, it would be reasonable to anticipate that **8a–c** and **9a–c** will not be formed.

Entries 9 and 12 provide an interesting direct qualitative comparison of the relative effectiveness of fulvene formation using in one case, diethylamine, and in the other, pyrrolidine; obviously, the latter is significantly more rapid and efficient.[19]

While we were able to obtain good to excellent yields for the preparation of a wide variety of structurally different fulvenes, we are disappointed to note that application of the methodology to the preparation of the fulvene derived from the optically pure tetrahydrofuranyl aldehyde **3** (entry 13) provided reasonably poor results, despite a great deal of effort. Thus, under all of the conditions attempted to date, no more than 45% of the optically pure fulvene was obtained.[20] Furthermore, the rate of fulvene formation is significantly slower than might have been anticipated based upon the fact that the starting material apparently does not possess any obvious structural features which should retard the desired process. Finally, it must be noted that some epimerization (12%) occurs during the reaction leading to fulvene **4**. Thus, the reaction affords a 51% yield of two readily separable diasteromeric fulvenes, 45% corresponding to the desired optically pure fulvene **4** and 6% to the diastereomer wherein epimerization has occurred. The problem of obtaining fulvene **4** in higher chemical yield and optical purity is still under active investigation.

## Experimental Section

The detailed experimental procedure presented here for the preparation of 6,6′-(pentamethylene)fulvene is representative of that used for the preparation of all of the fulvenes listed in Table I. Thus, only spectral data and modifications of this procedure are listed for the other entries. When necessary, the fulvenes were

(15) For examples of amine catalyzed proton abstraction from carbonyl compounds see: Roberts, R. D.; Ferran, H. E., Jr., Gula, M. J.; Spencer, T. A. *J. Am. Chem. Soc.* **1980**, *102*, 7054 and the references therein.

(16) The observed H–D exchange in the product fulvene has precedent. See, for example: Hine, J.; Knight, D. B. *J. Org. Chem.* **1980**, *45*, 991.

(17) Knight, D. B.; Hall, R. W.; Cleary, D. G. *J. Heterocycl. Chem.* **1981**, *18*, 1649.

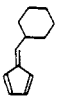
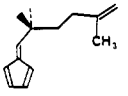
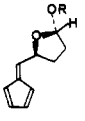
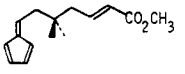
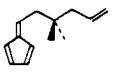
(18) For an informative discussion concerning $A^{1,3}$ interactions refer to: Johnson, F. *Chem. Rev.* **1968**, *68*, 375.

(19) A cautionary point must be made. That is, even though the use of pyrrolidine often leads to the rapid and efficient preparation of many different fulvenes, we have noted that when methyl (*E*)-6-oxo-2-hexenoate was used, pyrrolidine promoted fulvene formation (9%) and engaged in a Michael addition, thereby being incorporated into the product (ca., 20%). Unpublished results with Dr. O. Wallquist, UCSB. In most instances where we have prepared fulvenes starting with aldehydes bearing Michael acceptor units, we have been able to successfully use diethylamine.

(20) A higher yield of the trans fulvene **4** can be realized if the crude product is "derivatized" as its Diels–Alder adduct using bis(2,2,2-trichloroethyl) azodicarboxylate. After chromatography, a 50% yield of a pair of non-epimerized diastereomeric dicarbamates can be isolated. Refer to ref 6 for details.

(21) Otter, A.; Muhle, H.; Neuenschwander, M.; Kellerhals, H. P. *Helv. Chim. Acta* **1979**, *62*, 1626.

Table I

| entry | fulvene | rxn time | yield, % | lit. yield, % (ref) |
|---|---|---|---|---|
| 1 |  | 25 min | 96 | 38; 45 (7a; 8e) |
| 2 |  | 15 min | 93 | 27 (7a) |
| 3 |  | 15 min | 69 | 32 (7a) |
| 4 |  | 7.5 h | 77 | |
| 5 |  (6) | 2 h 15 min | 95 | 75 (17) |
| 6 |  (7) | 2 h | 86 | 42 (17) |
| 7 |  | 12 min | 81 | 95 (8t) |
| 8 |  | 1 h | 96 | |
| 9 |  | 15 min (pyrrolidine)<br>2.5 h ($Et_2NH$) | 98<br>45 | 49; 43 (7b; 8t) |
| 10 |  | 18 h | 90 | 42 (7b) |
| 11 |  | 17 h | 59 | 70 (3) |
| 12 |  | 4.5 h (pyrrolidine)<br>23 h ($Et_2NH$) | 70<br>45 | 66 (7b) |
| 13 |  <br>4 R = $SiMe_2t$-Bu | 48 h | 45 | (6) |
| 14 |  | 2 h ($Et_2NH$) | 91 | 2a |
| 15 |  | 2 h ($Et_2NH$) | 77 | 2c |

purified by chromatography on silica gel as noted.

**6,6-Pentamethylenefulvene[7a] (Entry 1).** To a solution of cyclohexanone (0.21 mL, 2.0 mmol) and cyclopentadiene (0.41 mL, 5.0 mmol) in reagent grade methanol (2 mL) was added pyrrolidine (0.25 mL, 3.0 mmol, freshly distilled under nitrogen). The mixture was stirred under nitrogen at room temperature. Analysis by TLC (E. M. Merck silica gel, Skelly Solve F (SSF), UV and *p*-anisaldehyde stain) showed no cyclohexanone after 15 min. Acetic acid (0.18 mL, 3.2 mmol) was added to the bright yellow solution after 25 min. The reaction mixture was diluted with ether and water (10 mL each). The aqueous portion was washed with ether (2 × 25 mL) and the combined organics were washed with water and brine (5 mL each), then dried over $MgSO_4$, and concentrated in vacuo (2 min at 2 torr) to afford 280 mg (96%) of pure 6,6-pentamethylenefulvene: TLC (SSF) $R_f$ 0.28; IR 3100, 3070, 2930, 2855, 1638, 1370, 1348, 856, 762, 680, 605 $cm^{-1}$; $^1H$ NMR (80 MHz) $\delta$ 6.53, 6.52 (appar d, 4 H), 2.64–2.57 (m, 4 H, allylic), 1.7–1.65 (m, 4 H); MS 146 ($M^+$), 131, 118, 117, 105, 104, 92, 91, 78.

**6,6-Tetramethylenefulvene[7a] (entry 2):** 15 min reaction time;

93% yield; chromatographed, TLC (SSF) $R_f$ 0.28; IR 2960, 1655, 1365, 760, 625 cm$^{-1}$; $^1$H NMR (300 MHz) $\delta$ 6.40 (m, 4 H), 2.80 (m, 4 H, allylic), 1.80 (m, 4 H); MS 132 ($M^+$), 131, 117, 115, 104, 91, 78, 65, 39.

**6,6-Trimethylenefulvene[7a] (entry 3):** 15 min reaction time; TLC (2% ether/SSF) $R_f$ 0.5; 65% yield; IR 3090, 3060, 2980, 2950, 2900, 2795, 1675, 1465, 1402, 1360, 1230, 1093, 1063, 1020, 910, 863, 805, 758, 702 cm$^{-1}$; $^1$H NMR (80 MHz) $\delta$ 6.5–6.2 (m, 4 H, vinyl), 3.11 (appar t, 4 H, $J$ = 7.6), 2.13 (appar q, 2 H, $J$ = 7.6).

**6,6-(2-Methylpentamethylene)fulvene (entry 4):** 7.5 h reaction time; 77% yield; 5 equiv of pyrrolidine; chromatographed, TLC (2% ether/SSF) $R_f$ 0.50; IR 3100, 3065, 2930, 2860, 1630, 1462, 1370, 1350, 1082, 927, 902, 888, 860, 842, 800, 760, 678, 628 cm$^{-1}$. $^1$H NMR (300 MHz) $\delta$ 6.61–6.48 (m, 4 H, 3.4–3.3) (m, 1 H, methine), 2.95–2.85 (appar d, 1 H, $J$ = 14, allylic), 2.45 (appar t, 1 H, $J$ = 4.8 , 13.5, allylic), 2.0–1.4 (m, 6 H, methylenes), 1.25 (d, 3 H, $J$ = 7.2, methyl); MS 161 (M + 1)$^+$, 160 ($M^+$), 145, 131, 117, 115, 92, 91, 78, 39. Anal. Calcd, 160.1252; found, 160.1252.

**4-Cyclopentadienylidenetetrahydrothiopyran (6)[17] (entry 5):** 2 h 15 min reaction time; TLC (10% ether/SSF) $R_f$ 0.50; chromatographed, 2% ether/SSF; 95% yield; IR 3102, 3072, 2968, 2910, 2850, 1725, 1726, 1640, 1467, 1430, 1420, 1380, 1368, 1322, 1290, 1232, 1148, 1130, 1110, 1094, 1024, 1003, 985, 950, 922, 895, 858, 828, 800, 768, 700, 680, 610 cm$^{-1}$; $^1$H NMR (80 MHz) $\delta$ 6.57 (s, 4 H), 3.15–2.75 (m, 8 H); MS 165 (M + 1)$^+$, 164 ($M^+$), 135, 117, 116, 1158 103, 91, 90, 89, 78, 77, 65, 63, 62, 51, 50, 46, 45, 38 27. Anal. Calcd, 164.0660; found, 164.0653.

**4-Cyclopentadienylidenetetrahydropyran (7)[17] (entry 6):** 1.5 h reaction time; 86% yield; chromatographed (10% ether/SSF); TLC (30% ether/Skellysolve F) $R_f$ 0.40; IR 3102, 3072, 2968, 2910, 2850, 1752, 1726, 1640, 1467, 1430, 1420, 1380, 1368, 1322, 1290, 1232, 1148, 1130, 1110, 1094, 1024, 1003, 685, 950, 922, 895, 858, 828, 800, 768, 700, 680, 610 cm$^{-1}$; $^1$H NMR (80 MHz) $\delta$ 6.51 (s, 4 H), 3.83 (t, 4 H, $J$ = 5.5, $CH_2OCH_2$), 2.74 (t, 4 H, allylic methylenes, $J$ = 5.5); MS 149 (M + 1)$^+$, 148 ($M^+$), 117, 115, 103, 91, 90, 89, 78, 77, 39. Anal. Calcd, 148.0888; found, 148.0892.

**6,6-Dimethylfulvene[8t] (entry 7):** 12 min reaction time; TLC (SSF) $R_f$ 0.34; chromatographed (SSF); 81% yield; $^1$H NMR (300 MHz) $\delta$ 6.53–6.45 (m, 4 H), 2.19 (s, 6 H).

**6-Cyclohexylfulvene (entry 8):** 1 h reaction time; quantitative yield; TLC (SSF) $R_f$ 0.40; IR 3100, 3070, 2920, 2850, 1648, 1475, 1447, 1380, 1334, 1068, 963, 898, 760, 610 cm$^{-1}$; $^1$H NMR (300 MHz) $\delta$ 6.53–6.15 (m, 5 H), 2.9–2.7 (m, 1 H), 2.0–1.1 (m, 10 H); MS 160 ($M^+$), 117, 104, 92, 91, 79, 78, 39. Anal. Calcd, 160.1252; Found, 160.1251.

**6-Isopropylfulvene[7b,8t] (entry 9):** 15 min rection time using pyrrolidine and 2.5 h using diethylamine; 98% after 15 min (pyrrolidine) and 45% after 2.5 h (diethylamine); IR 3100, 3070, 2960, 2865, 1650, 1465, 1335, 1078, 890, 760, 610 cm$^{-1}$; $^1$NMR (80 MHz) $\delta$ 6.53–6.10 (m, 5 H), 3.30–2.85 (m, 1 H), 1.12 (d, 6 H, $J$ = 6.6); MS 120 ($M^+$), 105, 45, 31, 27.

**6-*tert*-Butylfulvene[7b] (entry 10):** 18 h reaction time; 90% yield; chromatographed (SSF); IR 3075, 2960, 2905, 2870, 1635, 1475, 1460, 1396, 1380, 1362, 1342, 1215, 1090, 1080, 880, 760, 618 cm$^{-1}$; $^1$H NMR (300 MHz) $\delta$ 6.68–6.67 (m, 1 H), 6.60–6.57 (m, 1 H), 6.43 (br s, 1 H), 6.40–6.36 (m, 1 H), 6.17–6.14 (m, 1 H), 1.28 (s, 9 H); MS 134 ($M^+$), 119, 91, 77, 41, 39.

**6-(1,1,4-Trimethyl-4-pentenyl)fulvene[3] (entry 11):** 17 h reaction time; 59% yield; chromatographed; TLC (SSF) $R_f$ 0.32; IR 3070, 1630, 885 cm$^{-1}$; $^1$H NMR (300 MHz) $\delta$ 6.60–6.55 (m, 2 H), 6.40–6.30 (m, 2 H), 6.18–6.05 (7, 1 H), 4.70–4.60 (m, 2 H, $=CH_2$), 2.10–1.05 (m, 4 H, $CH_2CH_2$), 1.29 (s, 6 H, $CMe_2$). Anal. Calcd: C, 89.36; H, 10.63. Found: C, 89.15; H, 10.50.

**6-Phenylfulvene[7b] (entry 12):** 4.5 h reaction time using pyrrolidine and 23 h using diethylamine; TLC (pentane) $R_f$ 0.38; chromatographed; 70% after 4.5 h (pyrrolidine) and 45% after 23 h (diethylamine). Detailed spectral data can be found in ref 7b and 21.

**Optically pure fulvene 10 (entry 13):** 48 h reaction time; 5 equiv pyrrolidine; 45% trans and 6% cis; chromatographed (5% ether/SSF); TLC (10% ether/Skellysolve F) $R_f$ trans 0.55, cis 0.48; IR (cis) 3080, 2955, 2935, 2860, 1659, 1653, 1475, 1463, 1255, 1191, 1100, 995, 940, 896, 835, 778, 765, 615 cm$^{-1}$; $^1$H NMR (300 MHz) $\delta$ 6.54–6.52 (m, 1 H), 6.48–6.45 (m, 2 H), 6.385 (apparent d, 1 H, $C_6H$, $J$ = 9.0), 6.22–6.20 (m, 1 H), 5.526 (apparent d, 1 H, OCHO, $J$ = 3.0), 5.04–4.95 (m, 1 H, allylic CH), 2.20–1.90 (m, 4 H), 0.904 (s, 9 H, *t*-Bu), 0.123 (s, 3 H, SiMe), 0.111 (s, 3 H, SiMe); MS 279, 263, 221, 201, 199, 171, 147, 145, 129, 119, 117, 103, 91, 75, 73. Anal. MS [CI, $CH_5^+$ source] calcd, 279.1780 (M + 1)$^+$; found, 279.1781. For the trans isomer: IR 3080, 2960, 2935, 2860, 1660, 1654, 1483, 1475, 1465, 1345, 1260, 1255, 1193, 1090, 1022, 995, 898, 840, 780, 765, 615 cm$^{-1}$; $^1$H NMR (300 MHz) $\delta$ 6.55–6.47 (m, 2 H), 6.48–6.45 (m, 1 H), 6.281 (app d, 1 H, $C_6H$, $J$ = 8.1 Hz), 6.191 (app dt, 1 H, $J$ = 5.4, 1.5), 5.615 (app dd, 1 H, OCHO, $J$ = 4.5, 1.5), 5.168 (app td, 1 H, allylic CH, $J$ = 8.1, 6.3), 2.41–2.30 (m, 1 H), 2.15–2.05 (m, 1 H), 1.95–1.85 (m, 1 H, 1.80–1.68 (m, 1 H), 0.900 (s, 9 H, *t*-Bu), 0.119 (s, 6 H, $SiMe_2$); $[\alpha]_D^{25}$ (trans) +68.5 (*c* 1.55, $CHCl_3$). Anal. MS (CI) calcd, 279.1780 (M + 1)$^+$; found, 279.1808.

**Registry No.** 1 (E = $CO_2CH_3$), 89618-85-9; 2, 81331-92-2; 3, 87727-32-0; 4 (R = $SiMe_2Bu$-*t*), 87727-33-1; *cis*-4 (R = $SiMe_2Bu$-*t*), 89675-01-4; 6, 82235-10-7; 7, 82250-30-4; 6,6-pentamethylenefulvene, 3141-04-6; 6,6-tetramethylenefulvene, 4727-24-6; 6,6-trimethylenefulvene, 29183-43-5; 6,6-(2-methylpentamethylene)fulvene, 61039-47-2; 6,6-dimethylfulvene, 2175-91-9; 6-cyclohexylfulvene, 89618-84-8; 6-isopropylfulvene, 13912-68-0; 6-*tert*-butylfulvene, 24730-31-7; 6-phenylfulvene, 7338-50-3; 6-(2,2-dimethyl-4-pentenyl)fulvene, 89618-86-0; cyclopentadiene, 542-92-7; cyclohexanone, 108-94-1; cyclopentanone, 120-92-3; cyclobutanone, 1191-95-3; 2-methylcyclohexanone, 583-60-8; tetrahydrothiopyran-4-one, 1072-72-6; tetrahydropyran-4-one, 29943-42-8; acetone, 67-64-1; cyclohexanecarboxaldehyde, 2043-61-0; isobutyraldehyde, 78-84-2; pivalaldehyde, 630-19-3; 2,2,5-trimethyl-5-hexenal, 81331-91-1; benzaldehyde, 100-52-7; 3,3-dimethyl-6-(methoxycarbonyl)-5-hexenal, 89618-83-7; 3,3-dimethyl-5-hexenal, 39482-40-1; pyrrolidine, 123-75-1.

# A Simple Conversion of 2-Methoxynaphthoquinones to 2,3,4,5-Tetrahydronaphtho[1,2-*b*]furan-4,5-diones. Application to the Synthesis of (±)-Trypethelones

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Structures proposed for trypethelone, *O*-methyltrypethelone, and *O*-methyl-8-methoxytrypethelone have been confirmed by synthesis. The required naphthoquinone substrates were prepared regiospecifically in one step by using vinylogous ketene acetals and then converted to the desired products essentially in a novel one-flask procedure.

Recently several naphthoquinones were isolated from the mycosymbiont of *Trypethelium eluteriae* Sprengel and identified on spectral grounds as substituted dunniones.[1] In principle the structures of these substances could be

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