The observation of the 670-nm tautomer emission makes the luminescence study of the mechanism of the radiationless decay for 5HF feasible. Assuming that the thermally activated nonradiative transition is negligible at 18 K, the observed $\Phi \sim 2.3 \times 10^{-5}$ of the tautomer emission for 5HF is indicative of either a negligible yield of the ESIPT or the approximate unit efficiency of the $S'_1 \rightarrow T'_1$ intersystem crossing, resulting in the population of the T'_1 state. For the former case, an ultrafast $S_1 \rightarrow T_1$ intersystem crossing followed by $T_1 \rightarrow T'_1$ proton transfer was proposed by Merritt et al.[14] for the nonluminescent molecule *o*-hydroxybenzophenone. Both mechanisms should result in the population of the T'_1 state. On the basis of the long-wavelength $S'_1 \rightarrow S'_0$ emission, the $T'_1 \rightarrow S'_0$ phosphorescence is predicted to be in the near-infrared region. Therefore, this decay is believed to be dominated by radiationless pathways due to the small T'_1–S'_0 energy gap. Research focused on the dynamics of the triplet state of 5HF is currently in progress.

Registry No. 5HF, 491-78-1.

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Total Synthesis of (±)-Kempene-2

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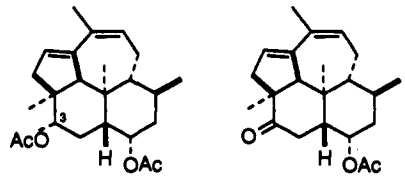
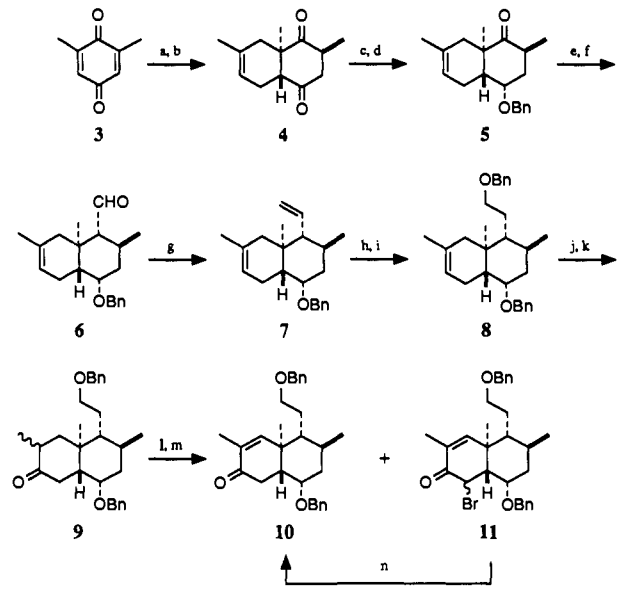
The cembrene-derived tetracyclic diterpenes kempene-1 (**1**), 3-*epi*-**1**, and kempene-2 (**2**) were isolated, along with other terpenes, from the defense secretion of termite soldiers, and their unique structure was determined by NMR studies and X-ray analysis.[1] We now report the first total synthesis of a member of this class of diterpenes. The synthesis of **2** (and therefore the formal synthesis of **1** and 3-*epi*-**1**)[1] utilized Diels–Alder cycloaddition as well as Ti^0-induced dicarbonyl coupling[2] for the formation of the tetracyclic skeleton.



1 **2**

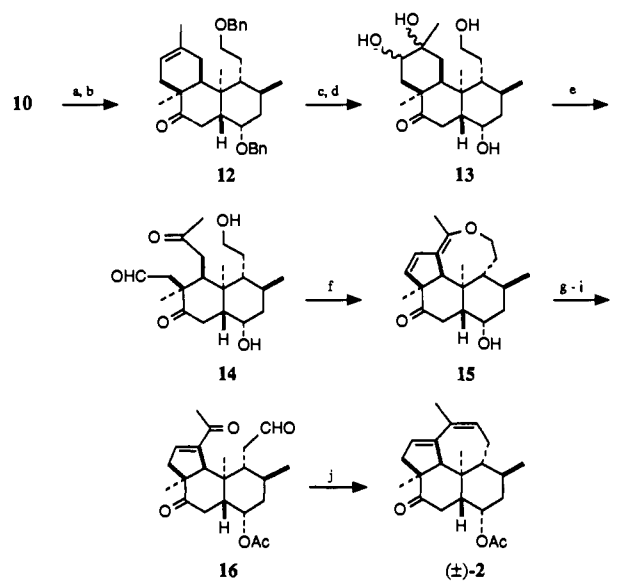
Reaction of 2,6-dimethylbenzoquinone (**3**) with isoprene (Scheme I) in the presence of $BF_3 \cdot Et_2O$ furnished a mixture of regioisomeric *cis*-decalins.[3] The quinone double bond was reduced under equilibrating conditions leading to stereoisomer **4**[4] as the major product, which was further purified by crystallization. LS-Selectride (Aldrich) in cold THF reduced the lesser hindered carbonyl to yield, after normal workup, the axial alcohol as a single isomer, which was converted into its benzyl ether **5**. Introduction of two carbons at the remaining hindered carbonyl function was accomplished by a Peterson type homologation[5] with 1-meth-

Scheme I[a]



[a] (a) $BF_3 \cdot Et_2O$, isoprene, 96 h. (b) Zn, HOAc reflux, 18 h, 13% from **3**. (c) LS-Selectride, THF, −78 °C, then 0 °C, NaOH, H_2O_2, 82%. (d) NaH, BnBr, Bu_4NI, THF, 72 h, 83%. (e) CH_3OCH_2TMS, *sec*-BuLi, THF, −60 °C to −20 °C, 1 h, then **5**, −40 °C, 30 min. (f) HCO_2H, EtOH, 73% from **5**. (g) CH_3PPh_3I, KOtBu, THF, 0 °C, 1 h, then **6**, room temperature, 18 h, 78%. (h) $HB(sia)_2$, THF, 40 °C, 72 h, then 0 °C, NaOH, H_2O_2, 82%. (i) NaH, BnBr, Bu_4NI, THF, 48 h, 98%. (j) BH_3·THF, 0 °C, 6 h, then NaOH, H_2O_2, 77%. (k) $(COCl)_2$, DMSO, CH_2Cl_2, 90%. (l) py·HBr·Br_2, THF, −78 °C, 30 min. (m) LiBr, Li_2CO_3, DMF, 120 °C, 16 h, 60% **10** and 23% **11**. (n) Bu_3SnH, AIBN, C_6H_6, reflux, 24 h, 53%.

Scheme II[a]



[a] (a) $EtAlCl_2$, toluene, 5 min, then isoprene, 80 °C, sealed tube, 24 h, 66%. (b) HPLC. (c) Cat. OsO_4, $(CH_3)_3NO$, $(CH_3)_2CO/H_2O$, 95%. (d) H_2, 10% Pd/C, AcOEt, 88%. (e) $NaIO_4$, dioxane/H_2O, 81%. (f) Cat. TsOH·H_2O, C_6H_6, 80 °C, 2 h, 61%. (g) Ac_2O, py, cat. DMAP, 66%. (h) HCl, EtOH, 80 °C, 2 h, 68%. (i) PCC/Al_2O_3, hexane/CH_2Cl_2, 57%. (j) $TiCl_3(DME)_{1.5}$, Zn–Cu, DME, reflux, 4 h, then **16** added over 12 h, 2-h reflux, 32%.

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(3) The ^1H NMR spectrum of the mixture of the cycloadducts as well as the mixture of the initial reduction products showed the presence of a *single* angular methyl group ($\delta \sim 1.2$ ppm), whereas after extended treatment with refluxing acetic acid, the angular methyl group signal appeared at $\delta \sim 0.9$ ppm, indicating the trans ring juncture.
(4) Satisfactory spectral and elemental (±0.4% C, H) or MS-analytical data were obtained for all major compounds listed in the manuscript.

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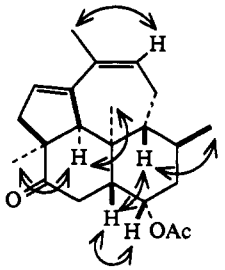

Figure 1. Critical observed NOE interactions for synthetic (±)-**2**.

oxy-1-(trimethylsilyl)methyllithium, conversion of the intermediate enol ether to the thermodynamically favored aldehyde **6**, and subsequent Wittig reaction to yield diolefin **7**. Selective hydroboration with disiamylborane[6] followed by oxidative workup gave the primary alcohol, which was converted into dibenzyl ether **8**. Hydroboration of the remaining double bond with diborane, followed by oxidation,[7] yielded **9** as a mixture of diastereomers, which was treated with pyridinium bromide perbromide in cold THF.[8] The resulting bromides were subjected to elimination to give **10** and **11** respectively. Bromo ketone **11** was converted into **10** by dehalogenation with Bu_3SnH.[9] Compound **10** contains five centers in the desired relative configuration and the requisite substituted enone required for the next annulation.

With enone **10** at hand, the construction of the five-membered ring was initiated, advantage being taken of the steric effect of the angular methyl group (Scheme II). As expected, cycloaddition of isoprene to **10** proved difficult but was eventually accomplished by using $EtAlCl_2$ as an acid catalyst[10] to give a mixture of two regioisomers favoring **12** by 2.6:1; their separation was accomplished by HPLC. No products arising from addition to the other face of **10** could be detected, thus, two more stereocenters were fixed. The double bond in **12** was dihydroxylated,[11] and the benzyl protecting groups were removed, furnishing tetrol **13** as a mixture of diastereomers. Glycol cleavage with $NaIO_4$ afforded labile **14**, which was converted upon treatment with acid into dienol ether **15**. The expected initial aldol product could not be isolated under any circumstances. However, the eight-membered-ring ether proved very useful as an intramolecular blocking group for the primary hydroxyl function.[12] Acetylation of **15** followed by hydrolysis of the enol ether and oxidation of the liberated primary alcohol gave enone aldehyde **16**. Finally, Ti^0-induced coupling[2] completed the construction of the tetracyclic skeleton to give (±)-kempene-2, which exhibited the same spectral properties as reported for the natural product.[1]

The correctness of the relative configuration at each stereocenter was further proven by a 2D-NOESY experiment (Figure 1). It is of particular interest that neither the carbonyl nor the ester moiety was affected by the last synthetic manipulation, confirming the utility of the Ti^0-induced coupling reaction in highly functionalized systems.

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Supplementary Material Available: Table with comparison of NMR data for both natural and synthetic **2** and 2D-COSY and NOESY spectra and MS for (±)-**2** (7 pages). Ordering information is given on any current masthead page.

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(12) Attempts to conduct the aldol reaction with protected hydroxyls failed.

DNA Modification: Intrinsic Selectivity of Nickel(II) Complexes

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Naturally occurring and laboratory-designed agents for DNA modification often rely upon transition-metal ions as promoters for nucleic acid oxidation.[1-8] Simple metal complexes may themselves show site specificity in their reactions with DNA based on (i) intercalative, groove-binding, or hydrogen-bonding interactions of the metal's ligands with the DNA[3-5] or (ii) the intrinsic reactivity of certain bases or sequences with the oxidant.[7] Alternatively, metal complexes may be tethered to known DNA-binding drugs or proteins in order to effect site specificity.[8] The identification of new metal complexes for reaction with DNA through nondiffusible species would aid in the development of new sequence-specific or conformation-specific DNA cleaving agents.

As our initial approach to this goal, we chose to investigate a series of square-planar nickel(II) complexes, some of which have been shown previously to catalyze oxygen atom transfer chemistry (e.g., olefin epoxidation) using iodosylbenzene, NaOCl, or $KHSO_5$ (oxone) as terminal oxidant.[9] Since, in the case of olefin epoxidation, the ability of Ni^{II} complexes to catalyze oxygen atom transfer was found to be highly ligand dependent, it suggested a course of study for the design of Ni^{II} complexes as catalysts for DNA oxidation. Interestingly, square-planar Ni^{II} complexes of tetraazamacrocycles such as the Schiff base complex NiL_1^{2+} and nickel cyclam, NiL_3^{2+}, were found to be highly active agents for DNA modification under oxidative conditions compared to related copper complexes or octahedral Ni^{II} complexes. Both $KHSO_5$ (oxone) and magnesium monoperoxyphthalate (MMPP) were effective as oxidants, but peracetic acid displayed a diminished activity and H_2O_2 with ascorbate was ineffective. Furthermore,

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(10) Metal complexes were prepared according to the following references. $[NiL_1](ClO_4)_2$ ((2,12-dimethyl-2,7,11,17-tetraazabicyclo[11.3.1]heptadeca-1(17),2,11,13,15-pentaene)nickel(II) perchlorate): Karn, J. L.; Busch, D. H. *Nature (London)* **1966**, *211*, 160-162. $[CuL_1][ZnCl_4]$: Rich, R. L.; Stucky, G. L. *Inorg. Nucl. Chem. Lett.* **1965**, *1*, 61-64. $[NiL_4][ZnCl_4]$ ((2,3-dimethyl-1,4,8,11-tetraazacyclotetradeca-1,3-diene)nickel(II) tetrachlorozincate): Tait, A. M.; Busch, D. H. *Inorg. Synth.* **1978**, *18*, 27-29. $[NiL_5](I)$ ((11,13-dimethyl-1,4,7,10-tetraazacyclotrideca-10,12-dienato)nickel(II) iodide): Cummings, S. C.; Sievers, R. E. *Inorg. Chem.* **1970**, *9*, 1131-1136. Other ligands were commercially available. Cyclam complexes, NiL_3 and CuL_3, were prepared as the bis-trifluoromethanesulfonate salts. Cyclen and tren complexes, NiL_6 and NiL_7, are discussed below.[13]

0002-7863/91/1513-5884$02.50/0