adding TME or CHD. Irradiation than caused rapid oxygen uptake. Also, luminescence behavior clearly demonstrated O_2 consumption, especially with the cyanide complexes. With O_2 present, emission was not visible; but if stirring was stopped, within ~5 sec a bright deep orange emission grew in as O_2 was consumed.

Quantitative photooxygenations at 0° used stirred methanol solutions containing a fixed amount of olefin (~3 mmol) and either 3 mg of Rose Bengal or 5 mg (5–10 μmol) of complex in ~30 ml. Oxygen uptakes (initially ~3–5 ml/min) ceased rather abruptly after ~15–30 min. Methanol was then removed by two flash evaporations with CCl_4. The oil, redissolved in CCl_4 and filtered, was characterized by ir.

Table II summarizes O_2 uptakes. Infrared spectra for a given olefin with all three sensitizers were indistinguishable and exhibited the same bands as the singlet oxygen–olefin reaction products.[1] $Ru(phen)_3^{2+}$ and $Ru(bipy)_2(CN)_2$ sensitizations exhibited similar uptakes; no quantitative data were taken.

The K_{sv}'s by the τ and ϕ methods for each $Ru(phen)_2(CN)_2$ and $Ru(bipy)_3^{2+}$ complex–solvent system are experimentally equal. Thus, O_2 quenching in these cases is principally diffusional and not from ground-state association. The k_2's which are all near the diffusion controlled limit indicate that a large fraction of encounters result in deactivation. We infer from the great structural similarity that the same conclusions hold for the remaining complexes.

Irradiation of Rose Bengal in the presence of oxygen is a clean, efficient source of singlet oxygen.[1,2] The Rose Bengal sensitized photooxygenations of TME and CHD proceed stoichiometrically (1:1) to yield unique and easily characterized products, a hydroperoxide and an *endo*-peroxide, respectively.[1] Thus, the Rose Bengal runs serve as analytical tests for the exact amount of olefin used and as an authentic source of the singlet oxygen addition products.

Table II shows that 1 mol of oxygen combines with 1 mol of TME or CHD for both metal complexes, the same as if singlet oxygen were the reactive species. This fact, coupled with the identification of the complex sensitized organic products as the singlet oxygen ones, leads to the conclusion that *singlet oxygen production is a significant pathway for oxygen deactivation of CT-triplet states of metal complexes.* This conclusion is based on the results for $Ru(bipy)_3^{2+}$ and $Ru(phen)_2(CN)_2$ in methanol. Since these two types of complexes are spectroscopically representative of a wide range of Ir(III),[8] Os(II),[9] and Ru(II)[10] complexes having lowest lying CT excited states, however, the phenomenon is probably a general one. One cannot necessarily generalize to d–d excited states. We have no quantitative data on the fraction of quenching events leading to energy transfer, but the similar rates of O_2 uptake for Rose Bengal and complex sensitization suggest that the efficiencies are high.

Metal complexes, because of their great resistance to uv photodestruction, may be useful as singlet oxygen generators for uv-rich sources or as sensitized actinometers. Further work on transfer efficiencies, olefins yielding multiple products, and other metal complexes is in progress.

Table II. Sensitized Oxygen Uptakes in Methanol at 0°

Sensitizer	Oxygen uptake (mmol)[a] 2,3-Dimethyl-2-butene	1,3-Cyclohexadiene
Rose Bengal[b]	3.09	3.12
$Ru(phen)_2(CN)_2$[c]	3.11	3.12
$Ru(bipy)_3^{2+}$[c]	3.08	3.17

[a] ~±1%. [b] With a 500-W DEK projection lamp, 5-cm water filter. [c] With a 1000-W Hg–Xe arc, 5-cm aqueous $CuSO_4 \cdot 5H_2O$ (100 g/l.).

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Synthesis of β-Hexa-, β-Hepta-, and β-Octaketones

Sir:

Recent interest in β-polycarbonyl compounds stems from their involvement in the biosynthesis of polyketide-type aromatic metabolites.[1] Numerous β-tetra- and two β-pentacarbonyl compounds have been synthesized, principally by stepwise acylation of the next smaller member.[2] This linear approach cannot, as yet, be carried beyond five carbonyl groups; a major problem being the difficulty of acetylating strongly basic anions.

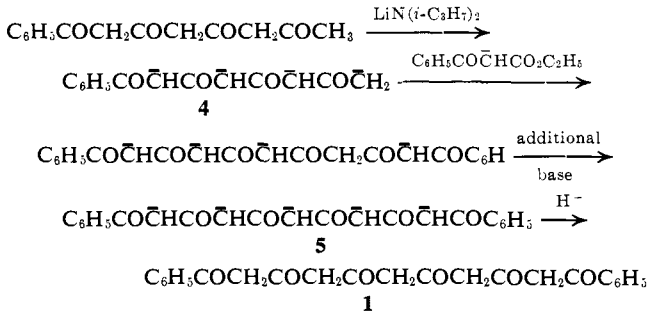
A recent communication from this laboratory described a novel approach to β-polyketones; β-tetra- and β-pentaketones were prepared by acylation of the polyanions of di- and triketones with β-keto ester monoanions.[3] These condensations, in effect, extend the ketide chains by two carbonyl groups. We now wish to describe the use of this β-ketoacylation reaction in the synthesis of higher polycarbonyl compounds, namely, 1,3,5,7,9,11-hexaketone **1**, 1,3,5,7,9,11,13-heptaketone **2**, and 1,3,5,7,9,11,13,15-octaketone **3**.

The initial approach to hexaketone **1** involved β-ketoacylation of 1-phenyl-1,3,5,7-octanetetraone with ethyl benzoylacetate (Scheme I). The tetraketone was treated with 4 equiv of lithium diisopropylamide in tetrahydrofuran (THF) at 0° under nitrogen, converting it into red tetraanion **4**. The sodium salt of the keto ester (formed with sodium hydride) was added in THF and the mixture was heated at 35°. After 2 hr, and again after 4, 8, and 10 hr, the mixture was cooled in an ice bath and 0.25 equiv of lithium diisopropylamide was

(1) For a review, see T. Money, *Chem. Rev.*, **70**, 533 (1970).
(2) (a) M. L. Miles, T. M. Harris, and C. R. Hauser, *J. Amer. Chem. Soc.*, **85**, 3884 (1963); (b) K. G. Hampton, T. M. Harris, C. M. Harris, and C. R. Hauser, *J. Org. Chem.*, **30**, 4263 (1965); (c) T. M. Harris and R. L. Carney, *J. Amer. Chem. Soc.*, **89**, 6734 (1967); (d) T. T. Howarth, G. P. Murphy, and T. M. Harris, *ibid.*, **91**, 517 (1969); (e) T. M. Harris and G. P. Murphy, *ibid.*, **93**, 6708 (1971).
(3) T. P. Murray and T. M. Harris, *ibid.*, **94**, 8253 (1972).

(8) R. J. Watts and G. A. Crosby, *J. Amer. Chem. Soc.*, **93**, 3184 (1971).
(9) G. A. Crosby, D. M. Klassen, and S. L. Sabath, *Mol. Cryst.*, 1, 453 (1966).
(10) J. N. Demas and G. A. Crosby, *J. Amer. Chem. Soc.*, **93**, 2841 (1971).

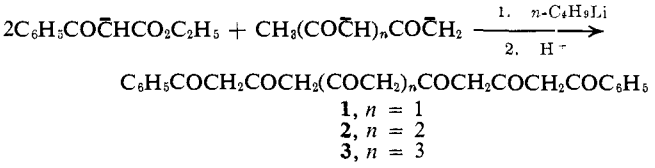
Scheme I



added.[4] After an additional 12 hr, the violet reaction mixture was worked-up in the usual fashion, employing chromatography on acidic silica gel and recrystallization from methylene chloride–ether–petroleum ether, to give 19% of hexaketone **1**, mp 91–95°.[5]

A more convenient and efficient method for the preparation of **1** is an *in situ* twofold β-ketoacylation of acetylacetone (Scheme II). Dilithioacetylacetone was

Scheme II



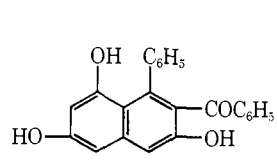
treated with 2 equiv of ethyl sodiobenzoylacetate employing a procedure similar to the above. After 4.5 hr at 50°, 1 equiv of *n*-butyllithium was added (with the mixture cooled to 0°) and, after subsequent intervals of heating, was followed by 2 additional equiv of this base. The procedure gave an improved yield (40%) of hexaketone **1**. Tetraketone is undoubtedly an intermediate in the reaction process, but it was not detected.

The twofold β-ketoacylation procedure was chosen for the synthesis of heptaketone **2** and octaketone **3**. Treatment of 2,4,6-heptanetrione and of 2,4,6,8-nonanetetraone with 2 equiv of ethyl benzoylacetate gave respectively 15% of heptaketone **2**, mp 97–101°, and 3% of octaketone **3**, mp 101–109°.[5] Mono-β-ketoacylation products were not detected in these cases either. The final reaction mixture in the synthesis of **2** was a deeper violet than the pentaanion of **1**, and the final mixture in the synthesis of **3** was still more deeply colored, reflecting the increasing lengths of the conjugated systems.

Polyketones **1–3** produce complex nmr spectra because they exist, at least in solution, as mixtures of many enol forms. The nmr spectrum of **1** (in $CDCl_3$) was somewhat simpler than those of **2** and **3**; the symmetrical 1,5,9-tris(enol) predominated over other tautomers. In spite of the complexity, the nmr spectra of **1–3** clearly support the assigned structures; isomeric formulations having terminal methyl groups are excluded by the absence of signals in the region of 2 ppm.

These polyketones should undergo numerous cyclization reactions, their ketide chains being long enough to make the compounds potential sources of naphthalene (and anthracene, as well, with octaketone **3**) derivatives. These reactions would represent interesting models of the biosynthesis of fused, polycyclic aromatic metabolites. Few biomimetic syntheses of fused polycyclics have been reported and none of these employs simple, intramolecular condensations of single, unencumbered polyketide chains.[6–8]

Preliminary studies of hexaketone **1** suggest that, in spite of the many cyclizations that are possible, good selectivity can be achieved with judiciously chosen conditions.[9] Four naphthalenetriols (**6–9**) could be formed



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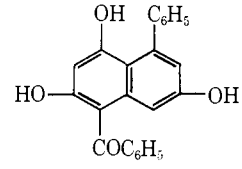

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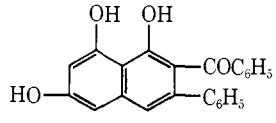

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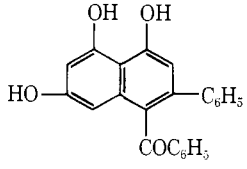

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by appropriate cyclizations of **1** and selective methods have been found by which two of these cyclizations can be effected.

Treatment of **1** with aqueous KOH gave mainly (70%) resorcinol **10**,[5] minor products being resorcinol **11** and its hemiketal (**12**),[5,11] mp 144–149° (Scheme III). Resorcinol **10** cyclized further in K_2CO_3 solution or in trifluoroacetic acid to give solely naphthalenetriol **6**; the compound was air-sensitive but could be isolated as the triacetate,[5] mp 156°, and trimethyl ether,[5] mp 151°. Cyclization of **10** might give either **6** or **7**. The first was shown to be the structure of the present product by independent synthesis of its trimethyl ether. The synthesis involved (1) acylation of the sodium salt of dibenzoylmethane with 3,5-dimethoxyphenylacetyl chloride, (2) cyclization of the triacylmethane with trifluoroacetic acid, and (3) methylation of the resulting 2-benzoyl-3-hydroxy-6,8-dimethoxy-1-phenylnaphthalene,[5] mp 197–198°, with dimethyl sulfate and potassium carbonate in acetone. It is noteworthy that in the nmr spectrum of the triacetate derivative of **6**, the

(4) The additional base was employed with the expectation that hexaketone **1** would exist as pentaanion **5** in the final reaction mixture (see Scheme I). Reionization of the product is a thermodynamic requirement in the acylation of enolate anions with simple esters and is assumed to be a requirement in the present case as well.

(5) The compound gave satisfactory elemental analyses and spectra that were consistent with the assigned structure.

(6) Self-condensation (intermolecular) of a β-triketone: J. N. Collie, *J. Chem. Soc.*, **63**, 329 (1893); J. N. Collie and N. T. M. Wilsmore, *ibid.*, **69**, 293 (1896); A. J. Birch, D. W. Cameron, and R. W. Rickards, *ibid.*, 4395 (1960); J. R. Bethell and P. Maitland, *ibid.*, 3751 (1962).

(7) Closure of the final ring: P. M. Baker and B. W. Bycroft, *Chem. Commun.*, 71 (1968); J. R. D. McCormick and E. R. Jensen, *J. Amer. Chem. Soc.*, **90**, 7126 (1968); J. R. D. McCormick, E. R. Jensen, N. H. Arnold, H. S. Corey, U. H. Joachim, S. Johnson, P. A. Miller, and N. O. Sjolander, *ibid.*, **90**, 7127 (1968).

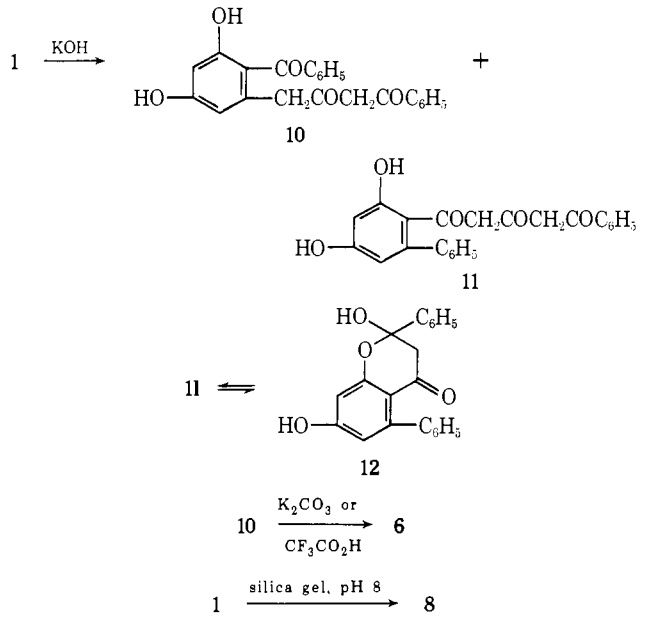
(8) Cleavage–recyclization reactions of complex pyrones, formally equivalent to polyketo acids: A. I. Scott, H. Guilford, and D. Skingle, *Tetrahedron*, **27**, 3039 (1971); A. I. Scott, D. G. Pike, J. J. Ryan, and H. Guilford, *ibid.*, **27**, 3051 (1971).

(9) The cyclizations of β-tetracarbonyl compounds and, to a lesser extent, β-pentacarbonyl compounds have been investigated.[2c–e,10] In most cases, high selectivity has been observed. However, with still larger ketide systems selectivity might diminish.

(10) T. T. Howarth and T. M. Harris, *J. Amer. Chem. Soc.*, **93**, 2506 (1971).

(11) Interconversion of **11** and **12** was sufficiently slow that a partial separation could be made by chromatography on silica gel. However, only **12**, which was less soluble than **11**, could be obtained pure by crystallization.

Scheme III



protons of the acetyl group peri to the phenyl substituent are highly shielded (δ 1.3). Ritchie and Taylor have described similar shielding of the acetyl protons of 1-acetoxy-8-phenylnaphthalene.[12]

By contrast with the above, treatment of **1** with silica gel (pH 8) gave 92% of **8**,[5] mp 240° dec (*in vacuo*). This naphthalenetriol is slightly air-sensitive but gives a stable triacetate,[5] mp 174°. The structure assignment for **8** rests primarily on the infrared spectrum which showed that the carbonyl group was intramolecularly hydrogen bound ($\nu_{C=O}$ 1630 cm^{-1}) and on the nmr spectrum of the triacetate derivative in which none of the acetate protons showed unusual shielding (δ 2.06, 2.29, 2.29). These observations exclude the other possible formulations for this naphthalenetriol. The compound is an analog of the aphid metabolite, 6-hydroxymusizin.[13]

Further studies of the formation of polycyclic aromatic compounds from polyketones **1–3** are in progress.

Acknowledgment. We are grateful for generous financial support by the U. S. Public Health Service (Research Grant GM-12848).

(12) E. Ritchie and W. C. Taylor, *Aust. J. Chem.*, **24**, 2137 (1971).
(13) K. S. Brown, D. W. Cameron, and U. Weiss, *Tetrahedron Lett.*, 471 (1969).
(14) National Defense Education Act Trainee.

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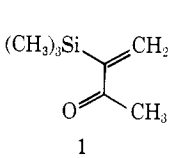
Conjugate Addition–Annelation. A Highly Regiospecific and Stereospecific Synthesis of Polycyclic Ketones

Sir:

The regiospecific addition of vinyl ketones to kinetically generated enolates under the usual aprotic conditions has heretofore not been feasible due to two factors: (1) the extensive polymerization of vinyl ketones under these aprotic conditions and (2) relatively rapid proton transfer involving the vinyl ketones resulting in loss of enolate regiospecificity. Recently, Stork and Ganem[1] have introduced the α-silylated vinyl ketones as reagents designed to obviate the polymerization problem. However, they were unable to avoid extensive enolate equilibration in regio-unstable enolates.

During the course of a study of the chemistry of organocopper enolates,[2] we have found them regiochemically stable during alkylation reactions in all but the most hindered situations.[3] We were led to investigate the utility of the α-silylated vinyl ketones in combination with the lowered basicity and high enolate regiostability of organocopper enolates as a solution to the problem of annelation of regio-unstable kinetically generated enolates. At present the most convenient method of generation of copper enolates is *via* conjugate addition of lithium organocuprates.[4] A prior study of this overall process was beset by the aforementioned problems.[5]

Methyl-α-trimethylsilyl vinyl ketone (α-silyl-MVK) (**1**) (bp 72° (50 mm); 63%) was synthesized by a route analogous to that of Stork and Ganem.[6] Addition of cyclohexenone (1 equiv) to a solution of lithium dimethylcuprate (1 mol equiv) in ether at 0° for 1 hr followed by an ether solution of **1** (1 equiv) at −78°, stirring at −20° for an additional 1 hr, and quenching with aqueous ammonium chloride resulted in the isolation of a mixture of substances, primarily **2**, in good



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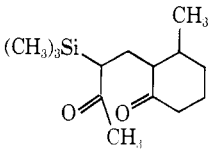

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yield. The structure of **2** was inferred from the ir spectrum of the mixture which exhibited carbonyl absorption at 1715 cm^{-1}, as well as the characteristic singlet absorptions due to the methyl ketone δ 2.00 and trimethylsilyl δ 0.10 groups in the nmr spectrum. Further treatment of this crude mixture with 2% potassium hydroxide in methanol at reflux for 1 hr gave octalone **3** in 52% overall yield.[7] The structure of **3** was rigorously established by spectral comparison with the authentic octalone[8,9] and isomeric purity by comparison with **3** and **4** prepared as a mixture (23:77) from the enamine of 3-methylcyclohexanone and methyl

(1) G. Stork and B. Ganem, *J. Amer. Chem. Soc.*, **95**, 6152 (1973).
(2) We are currently pursuing direct evidence regarding the structure of the intermediates of 1,4 addition to α,β-unsaturated ketones; nevertheless we have noted distinct differences in the reactivity of these species compared to the corresponding lithium enolates; see also G. H. Posner and J. J. Sterling, *J. Amer. Chem. Soc.*, **95**, 3076 (1973).
(3) R. K. Boeckman, Jr., *J. Org. Chem.*, in press.
(4) Preliminary indications are that the organocopper enolate species generated by exchange have different reactivity and possibly differ structurally; see G. H. Posner, *Org. React.*, **19**, 1 (1972).
(5) R. A. Kretchmer, E. D. Hihelich, and J. J. Waldron, *J. Org. Chem.*, **37**, 4483 (1972).
(6) B. Ganem, Ph.D. Dissertation, Columbia University, 1972.
(7) All compounds reported had satisfactory ir, nmr, and mass spectral data. Yields reported are for distilled material (Kugelrohr).
(8) We wish to thank Professor W. G. Dauben for providing spectral data of authentic **3** (equilibrium mixture of α,β and β,γ isomers) for comparison; see also R. A. Kretchmer and W. M. Schafer, *J. Org. Chem.*, **38**, 95 (1973).
(9) The formation of **3** under equilibrating conditions seems to suggest that the thermodynamically favored equatorial isomer shown is the primary product. However, it is possible that small amounts of the epimeric methyl ketone are present. In any case, reactions done under conditions which equilibrate the isomers make this center potentially labile.