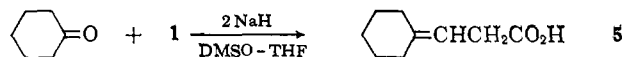
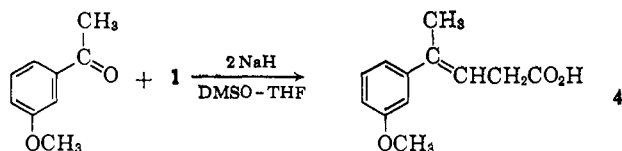


the intermediate ylide from the phosphonium halide⁶ gave only traces of desired acidic product. This is probably due to the elimination of triphenylphosphine to form acrylic acid. Yields of about 10% of 4-(*m*-methoxyphenyl)-3-pentenoic acid (**4**) were obtained sporadically when *m*-methoxyacetophenone was added to a solution of sodium methylsulfinylcarbanion⁷ prior to the addition of **1**. However, when equivalent quantities of the ketone and **1** were dissolved in 1:1 DMSO-tetrahydrofuran and added to dry sodium hydride under nitrogen at 0°, the yields increased to above 50%. This procedure has afforded crude **4** in the range of 53–69% yield with reaction times of 4 and 18 hr. The crude product has been recrystallized from cyclohexane to give **4**, melting at 86–87°. *Anal.* Found: C, 69.66; H, 6.62; neut. equiv., 206.



Cyclohexanone reacted with **1** to yield 66% of β -cyclohexylidenepropionic acid (**5**) as an amber liquid which was distilled over as short path [105° (0.35 mm.)] to give a clear crystalline solid (m.p. 37–39°). *Anal.* Found: C, 70.31; H, 9.45; neut. equiv., 158.

The structures of **4** and **5** were established by their n.m.r. spectra. The spectrum for **4** (m.p. 86–87°) showed a doublet for the methyl at 123 c.p.s. ($J = 1$ c.p.s.), which is appropriate for a methyl attached to a trisubstituted double bond with the proton on the adjacent olefinic carbon.⁸ There was a single olefinic proton which showed a triplet centered about 357 c.p.s. Only structure **4** fits this n.m.r. pattern.

The n.m.r. spectrum obtained for **5** was best interpreted in terms of the structure indicated. The two hydrogens in the position α to the carboxyl and adjacent to the double bond appeared as a doublet at 186 c.p.s. ($J = 7$ c.p.s.). The other four allylic hydrogens formed a band envelope at 128 c.p.s. There was one olefinic proton with a triplet at 315 c.p.s. The allylic proton pattern excluded the presence of an endocyclic double bond and the triplet of the olefinic proton showed that the isomeric β -cyclohexylacrylic acid was not present.

The melting range (58–72°) of crude **4** indicated that a mixture of isomers had been obtained. This was confirmed by gas-liquid chromatography (g.l.c. done in a 0.5 in. \times 5 ft. column of 1.5% SE-30 on Gas Chrom-2 in a Perkin-Elmer vapor fractometer, Model 154, at 156° and a helium flow setting of 120 on the rotameter) of the methyl esters, prepared by treatment of the acids with ethereal diazomethane, which showed

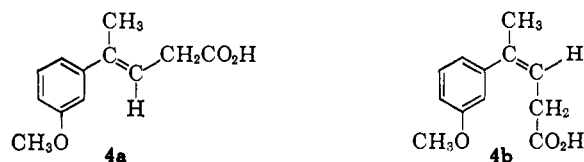
(6) R. Greenwald, M. Chaykovsky, and E. J. Corey, *J. Org. Chem.*, **28**, 1128 (1963).

(7) E. J. Corey and M. Chaykovsky, *J. Am. Chem. Soc.*, **84**, 866 (1962).

(8) L. M. Jackman, "Nuclear Magnetic Resonance Spectroscopy," Pergamon Press, New York, N. Y., 1959, p. 85.

74–80% of the crude Wittig products to be in a peak with a retention time of 4.80–5.04 min. and 19–24% in a second peak at 2.90–3.02 min. Two or three minor components accounted for 1–2% of the mixtures. The g.l.c. of the ester of the microanalytical sample of crystalline **4** demonstrated that it was homogeneous and that it had the retention time of 4.80–5.04 min. Similar analysis of a liquid mixture recovered from recrystallization mother liquors showed that it contained predominantly the substance with the 2.90–3.02 min. retention time and also about 20% of the ester of the crystalline isomer. The n.m.r. spectra confirmed that the crystalline isomer and the predominant component of the noncrystalline mixture were geometric isomers.

Ultraviolet spectral comparison of the crystalline and noncrystalline products suggested that the crystalline **4** is *trans* [**4a**, λ_{max} 286 m μ (ϵ 2319)] and that the predominant component of the liquid mixture is *cis* [**4b**, λ_{max} 281 m μ (ϵ 2171)].⁹



Continuing studies have extended the scope of this application of the Wittig reaction to other carbonyl reactants and phosphonium halides. The β , γ -unsaturated acids are being investigated for themselves and as intermediates in further synthesis.

(9) Since both the λ_{max} and ϵ_{max} values of the crystalline isomer are greater than for the mixture in which the other isomer is predominant, we feel that the conclusion of C. N. R. Rao ("Ultraviolet and Visible Spectroscopy," Butterworths, Inc., London, 1961, p. 69) that the absorption intensities of long wave length bands of *trans* isomers are always greater than those of the corresponding *cis* isomers may be applied here. We feel justified in using ϵ_{max} for the mixture since, upon hydrogenation, it gave the single product 4-(*m*-methoxyphenyl)valeric acid (homogeneous by g.l.c.), also obtained from crude Wittig reaction products, and from the homogeneous crystalline isomer. It is our assumption that the interaction between the phenyl group and the carboxymethyl group would have a more pronounced effect upon the coplanarity of the double bond and the benzene ring than the interaction between the methyl and carboxymethyl.

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RECEIVED FEBRUARY 24, 1964

2-*exo,cis*-Bicyclo[3.3.0]octane Derivatives via Free-Radical Additions to *cis,cis*-1,5-Cyclooctadiene^{1,2}

Sir:

While ionic^{3,4} and carbene⁴ reactions of cyclic systems usually lead to transannular rearrangements, with the exception of bicyclo[2.2.1]heptadiene⁵ (a homoallylic system), analogous free-radical reactions are unknown. It has now been found that only 2-*exo,cis*-bicyclo[3.3.0]octane derivatives are formed by free-radical additions to *cis,cis*-1,5-cyclooctadiene.

(1) This work was supported in part by a research grant (GM 11499-01) from the National Institutes of Health.

(2) Complementary results are found in the work of R. Dowbenko, *J. Am. Chem. Soc.*, **86**, 946 (1964).

(3) E.g., A. C. Cope, J. N. Grisar, and P. E. Peterson, *J. Am. Chem. Soc.*, **82**, 4299 (1960).

(4) (a) L. Friedman and H. Shechter, *ibid.*, **83**, 3159 (1961); (b) *ibid.*, ref. 5a-j.

(5) D. J. Trecker and J. P. Henry, *ibid.*, **85**, 3204 (1963); for a bibliography of such reactions, see ref. 3–8 contained therein.

A solution of *cis,cis*-1,5-cyclooctadiene (90 g., 0.833 mole) and *t*-butyl peroxide (11.0 g., 0.075 mole) was added over a period of 24 hr. to a heated ($137 \pm 2^\circ$) stirred mixture of *t*-butylformamide⁶ (3.03 kg., 30 moles), *cis,cis*-1,5-cyclooctadiene (18 g., 0.167 mole), and *t*-butyl peroxide (2.92 g., 0.02 mole). After removal of peroxide decomposition products (acetone, *t*-butyl alcohol), unchanged *cis,cis*-1,5-cyclooctadiene (~ 5 g.), and *t*-butylformamide by distillation, the dark-colored residue was treated with heptane to give crude (95–120 g., 46–57%)⁷ *N-t*-butyl-*exo,cis*-bicyclo[3.3.0]octane-2-carboxamide (I) (m.p. 130–134°) which after recrystallization from pentane or sublimation melted at 134–135°⁸; λ_{\max} 3.08, 3.30, 6.11, 6.48 μ . N.m.r. analysis⁹ showed a single peak at 5.31 p.p.m. (NH proton), a broad peak centered at 2.53 p.p.m. (attributable in part to C-2 proton), several unassigned peaks between 1.51 and 1.8 p.p.m. (CH₂ protons), and a sharp single peak at 1.29 p.p.m. (CH₃ protons). *N-t*-Butylcyclooctanecarboxamide, m.p. 150–151° (prepared from cyclooctene and *N-t*-butylformamide), showed a singlet at 5.24 p.p.m. (NH proton), no peak at 2.53 p.p.m., a broad ill-defined peak from 1.53 (max.) to 1.8 p.p.m. (CH₂ protons), and a sharp singlet at 1.29 p.p.m. (CH₃ protons). The n.m.r. spectra are easily distinguishable.

All attempts¹⁰ to saponify I were fruitless. Authentic I prepared from the authentic precursor acid¹¹ (*via* the acid chloride) and *t*-butylamine was indistinguishable from the free-radical product (n.m.r., infrared, melting point, mixture melting point).

Reaction of *cis,cis*-1,5-cyclooctadiene with methyl formate¹² and dimethylformamide⁶ in the presence of *t*-butyl peroxide gave in low yield the expected methyl *exo,cis*-bicyclo[3.3.0]octane-2-carboxylate and a 1:1 mixture of *N,N*-dimethyl-*exo,cis*-bicyclo[3.3.0]octane-2-carboxamide and *N*-methyl-*N*-formyl-*exo,cis*-bicyclo[3.3.0]octane-2-methylamine, respectively.

Diethyl⁵ (and dibutyl) phosphonate and *cis,cis*-1,5-cyclooctadiene in the presence of *t*-butyl peroxide gave diethyl *exo,cis*-bicyclo[3.3.0]octane-2-phosphonate (60%, b.p. 92–94° at 0.5 mm., n_D^{25} 1.4680) and the corresponding dibutyl ester (55%, b.p. 126° at 0.3 mm., n_D^{25} 1.4650). Extended hydrolysis in a hydrochloric-acetic acid mixture gave *exo,cis*-bicyclo[3.3.0]octane-2-phosphonic acid, m.p. 101.5–102.5°. N.m.r. analysis⁹ on the ethyl ester showed a quartet centered at 1.3 p.p.m. (CH₃ protons in ethyl group), a broad peak centered at 2.48 p.p.m. (in part due to C-2 proton), and other unassigned peaks from 1.55 (max.) to 2.0 p.p.m. (CH₂ protons in ring, etc.). The butyl ester showed a quartet centered at 3.93 p.p.m. (CH₂ protons in butoxy group), a broad peak centered at 2.54 p.p.m. (C-2 proton), and other unassigned peaks from 1.55 (max.) to 2.0 p.p.m. The free acid showed a sharp peak at 11.6 p.p.m. (acid protons), a broad peak centered at 2.52 p.p.m. (C-2 proton), complete

(6) L. Friedman and H. Shechter, *Tetrahedron Letters*, 238 (1961).

(7) The residue consisted of higher telomers, presumably *N-t*-butylpoly(bicyclo[3.3.0]octane)-2-carboxamide (n.m.r. analysis).

(8) Satisfactory elemental analyses were obtained for all new compounds.

(9) The assistance of Dr. W. R. Ritchey, Research Laboratories, Standard Oil Co., Ohio is gratefully acknowledged.

(10) Fused potassium hydroxide at 200°; potassium hydroxide in triethanolamine at 250°; phosphoric acid at 100, 150°; polyphosphoric acid at 120°: at 200° total destruction of the amide occurred.

(11) A. C. Cope and M. Brown, *J. Am. Chem. Soc.*, **80**, 2859 (1958).

(12) W. H. Urry and E. S. Huyser, *ibid.*, **75**, 4876 (1953).

absence of vinyl protons, and unassigned peaks between 1.55 and 2.0 p.p.m. Cyclooctanephosphonic acid did not display a peak at 2.52 p.p.m. The phosphonic acid and esters are inert toward the usual oxidizing agents, bromine, and hydrogen over palladium.

The generality of free-radical cyclo-additions to *cis,cis*-1,5-cyclooctadiene was further established by reactions with acetaldehyde, thiophenol, and piperidine.

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RECEIVED FEBRUARY 28, 1964

On the Formation of Pyrophosphate from Quinol Phosphates in Dimethylformamide Solution

Sir:

Quinol phosphates have been suggested¹ as the active agents for oxidative phosphorylation in biological systems. In the presence of an oxidizing agent, such as air or bromine, various naphthalenediol phosphates have been shown^{2,3} to be capable of phosphorylating alcohols and other substrates. However, it was found,⁴ using a solvent enriched in oxygen-18, that the breakdown of a model compound, 2,3-dimethylnaphthalenediol 1-phosphate (4-hydroxy-2,3-dimethyl 1-phosphate, I), undergoes "oxidative hydrolysis" in a complex fashion, only 30% of the phosphate being produced in the form of metaphosphate, the phosphorylating entity.

In order to study this reaction under simpler and more easily controlled conditions, it has now been run in an anhydrous solvent. On adding excess bromine to a solution of I in dry dimethylformamide (DMF) in which an equimolar quantity of tetrabutylammonium phosphate was dissolved, almost one-third of the liberated phosphate is in the form of pyrophosphate. In the *absence* of added phosphate, an even higher yield of pyrophosphate and condensed phosphorus acids is formed, as shown in Table I. Similarly,

TABLE I
YIELD OF INORGANIC PHOSPHATE AND CONDENSED PHOSPHATE IN DRY DMF

Quinol phosphate	Added substrate	% phosphate ^c	% condensed phosphate ^d
I ^a	None	52.5	47.5
I ^b	Bis(tetrabutylammonium) hydrogen phosphate	69	31
V ^b	Bis(tetrabutylammonium) hydrogen phosphate	68	32

^a Bromine (0.8 ml.) was added to a dry DMF solution (50 ml.) of quinol phosphate (1.3 g.) at room temperature. After 1 hr., cyclohexene was added to absorb excess bromine; water was then added (50 ml.) and the organic matter was extracted with ether. A mixture of phosphates was precipitated from the aqueous layer with BaCl₂ at pH 7–8. ^b Experimental conditions as described above with addition of bis(tetrabutylammonium) phosphate (1.65 g.). Paper chromatography indicated that only phosphate and pyrophosphate are formed in the presence of added inorganic phosphate. ^c Analyzed colorimetrically by the method Fiske and Subbarow.⁵ ^d Total phosphate analyzed colorimetrically after 20-min. hydrolysis at 100° and per cent condensed phosphates calculated by difference.

(1) V. M. Clark, G. W. Kirby, and A. R. Todd, *Nature*, **181**, 1650 (1958).

(2) K. J. M. Andrews, *J. Chem. Soc.*, 1808 (1961).

(3) V. M. Clark, D. W. Hutchinson, G. W. Kirby, and A. R. Todd, *ibid.*, 715 (1961).

(4) A. Lapidot and D. Samuel, *Biochim. Biophys. Acta*, **65**, 164 (1962).