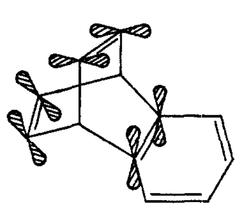
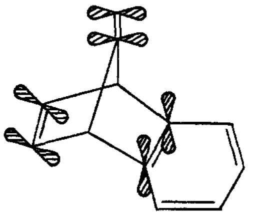
vide chemical confirmation for the structure of **3** and a convenient preparative method for **5**.

The chemistry of bicyclo[2.2.2]octatriene (barrelene) and its benzo analog, benzobicyclo[2.2.2]octatriene (**6**) has received considerable attentions.[5,6] The parent compound of **3**, 7-methylenebenzonorbornadiene (**7**), would be regarded as a valence-bond isomer of **6**. From this standpoint, a detailed account of the ultraviolet absorption maxima of **3** is listed in Table I, along with those of some related compounds. Of considerable interest is that red-shifted maxima and increased extinction coefficients were observed in **3** when compared with those in **6**, but a detailed research on this finding will be postponed until the parent compounds such as 7-methylenenorbornadiene and **7** are synthesized.



6



7

Experimental Section[7]

7-Isopropylidenebenzonorbornadiene (3a).—A solution of 87.5 g of *o*-bromofluorobenzene (**2a**) and 52.4 g of 6,6-dimethylfulvene (**1**) in 600 ml of anhydrous tetrahydrofuran was added dropwise onto 12.2 g of magnesium turning with vigorous stirring under nitrogen atmosphere. The dropping was adjusted at such a rate as to maintain a gentle reflux. After the addition, refluxing of the reaction mixture was further continued for about 30 min. The tetrahydrofuran was removed under reduced pressure and the residue was poured into water and extracted with ether. The ether extract was washed with water, dried over sodium sulfate, and evaporated. The residue obtained was solidified on cooling and filtered. Washing of the crystals with cold ethanol yielded 22 g of **3a**, mp 91–91.5°. Distillation of the unsolidified filtrate gave a fraction at bp 97–103° (4 mm), which on standing was solidified and recrystallized from ethanol to give 6.3 g of pure **3a**. The total yield was 31.4%. The infrared spectrum showed $\nu_{max}^{CCl_4}$ 680 (vs), 696 (m), 1011 (m), 1088 (m), 1221 (m), 1293 (m), 1298 (m), 1373 (m), 1448 (vs), 2851 (m), 2911 (s), 3007 (s), and 3071 (m) cm^{-1}.

Essentially the same procedure was applied for the preparation of **3b–3e**. Analyses and properties of **3** and **4** are summarized in Table II.

7-Isopropylidenebenzonorbornene (4a).—Catalytic reduction of **3a** was carried out over palladium on charcoal with the absorption of 1 mole of hydrogen under ice cooling. The usual work-up procedure gave crystals **4a**. The infrared spectrum showed $\nu_{max}^{CCl_4}$ 691 (vs), 837 (m), 1011 (m), 1112 (vs), 1154 (m), 1288 (m), 1373 (m), 1443 (vs), 1498 (s), 1466 (s), 2860 (s), 2920 (vs), 2980 (vs), and 3060 (m) cm^{-1}. Uptake of the second mole of hydrogen was much slower, so that the control of selective hydrogenation of the two double bonds in **3** was easy.

Ozone Oxidation of 4a.—Oxygen containing 23 mg l.$^{-1}$ of ozone was passed into a solution of 21.5 g of **4a** in 400 ml of dichloromethane under cooling in a salt–ice bath. The gas passed through the reaction vessel was bubbled into a 1% potassium iodide solution. The flow of oxygen was adjusted at such a rate that no color was observed in the potassium iodide solution. After about 6 hr, the test solution of potassium iodide began to show a faint yellow color. The oxygen was further introduced for 40 min into the reaction mixture. To remove the excess of ozone dissolved in the solution, nitrogen was introduced. In order to destroy the ozonide, acetic acid (60 ml) was slowly added to the solution with stirring, then 20 g of zinc powder and 2.0 ml of water was added portionwise and in an alternative manner, and the solution was allowed to stand at room temperature. Survival of the ozonide was examined with 1 drop of the above solution by an iodide–starch paper. The solution was extracted with ether, and the ether solution was washed with water and aqueous sodium bicarbonate, and dried. After removal of the solvent, the residue obtained was distilled to give 13.7 g (74%) of **5a** at bp 100–103° (7 mm). Its infrared spectrum in CCl_4 showed bands at 3006 (m), 2940 (m), 1806 (s), 1792 (vs), 1470 (m), 1134 (m), 1119 (m), and 885 (m) cm^{-1}.

TABLE II

ANALYSES AND PROPERTIES OF **3** AND **4**

Compd	Mp or bp (mm), °C, and n_D (temp, °C)	Formula	Carbon, % Calcd	Carbon, % Found	Hydrogen, % Calcd	Hydrogen, % Found
3a	91-91.5	$C_{14}H_{14}$	92.26	92.57	7.74	7.92
3b	108-110 (3) 1.5650 (25)	$C_{15}H_{16}$	91.78	92.07	8.22	8.31
3c	64.5–65	$C_{14}H_{13}Cl$	77.59	77.67	6.05	6.10
3d	70-71	$C_{14}H_{13}F$	83.69	83.89	6.54	6.30
3e	74.5–75.5	$C_{15}H_{16}O$	84.87	84.89	7.60	7.72
4a	90.5–91.5	$C_{14}H_{16}$	91.21	91.33	8.75	8.79
4b	120–122 (8) 1.5530 (24)	$C_{15}H_{14}$	90.85	91.07	9.15	9.36
4c	124–125 (6) 1.5694 (24)	$C_{14}H_{15}Cl$	76.87	76.65	6.91	6.88
4d	48–49	$C_{14}H_{15}F$	83.16	83.11	7.43	7.21

Identification of 5 was carried out by comparison of physical properties including infrared spectra with authentic samples (**5a**,[2a,8] **5b**,[2b] **5c**[2b] and **5e**[2b]) prepared by the Oppenauer oxidation of the corresponding *anti*-7-benzonorbornenols.[2a]

The new ketone **5d** had bp 95–97 (3 mm), $n^{24.5}D$ 1.5404, and $\nu_{max}^{CCl_4}$ 3017 (m), 2982 (m), 2957 (m), 2887 (m), 1802 (sh) (s), 1790 (vs), 1622 (m), 1592 (m), 1482 (s), 1462 (m), 1278 (m), 1243 (m), 1226 (m), 1115 (m), 934 (m), 880 (m), and 870 (m) cm^{-1}.

Anal. Calcd for $C_{11}H_9FO$: C, 74.98; H, 5.15. Found: C, 75.17; H, 5.04.

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[5] H. E. Zimmerman and R. M. Paufler, *J. Am. Chem. Soc.*, **82**, 1514 (1960); H. E. Zimmerman and G. L. Grunwald, *ibid.*, **86**, 1434 (1964).

[6] R. G. Miller and M. Stiles, *ibid.*, **85**, 1798 (1963).

[7] Melting points were taken by capillary and are corrected. Boiling points are uncorrected. Ultraviolet spectra were determined with a Beckman DK-2A spectrophotometer. Infrared spectra were recorded on a Nippon Banko IR-S spectrometer in carbon tetrachloride. Nmr spectra were determined at 60 Mc with Varian A-60 spectrometer using tetramethylsilane as internal standard.

[8] P. D. Bartlett and W. P. Giddings, *J. Am. Chem. Soc.*, **82**, 1240 (1960).

Bicyclic Ketones by Intramolecular Alkylations. A Reinvestigation

SARAH JANE ETHEREDGE[1]

The Chandler Laboratories of Columbia University, New York 25, New York

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Treatment of the substituted ketones I-III with base can, in theory, give rise in each case to two products of intramolecular C-alkylation and I and II (Chart I) can also give a product of intramolecular O-alkylation. This last possibility is prohibited in III because the resulting enol ether would have a double bond at the bridgehead.[2]

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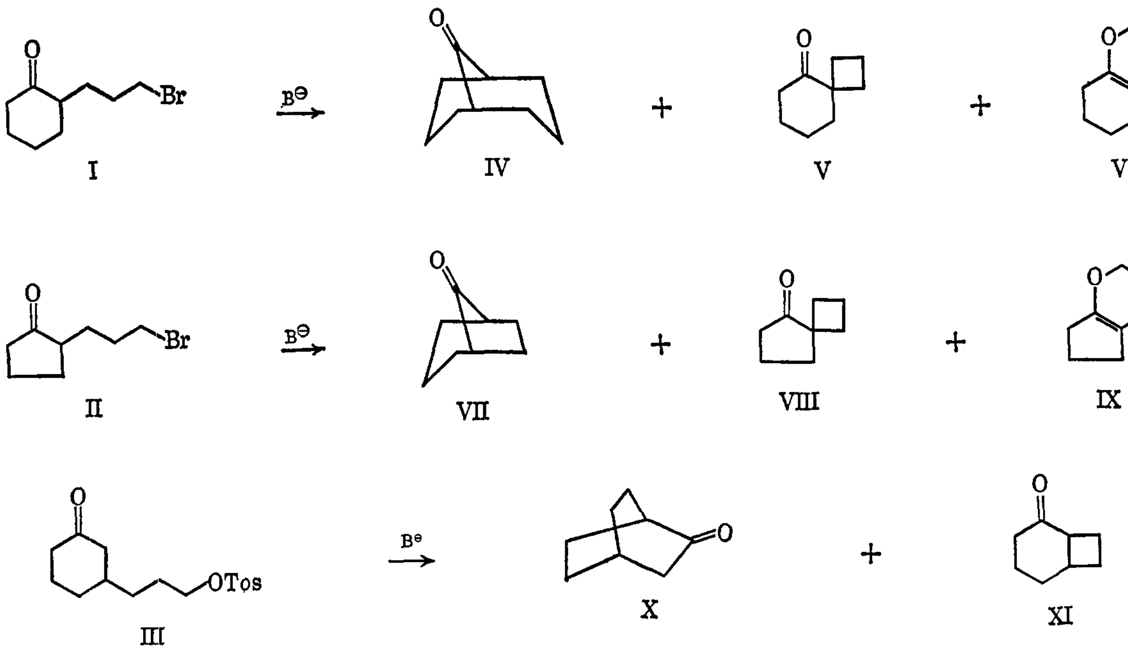
[1] Correspondence should be addressed to the author: Ben May Laboratory for Cancer Research, University of Chicago, Chicago, Illinois 60637.

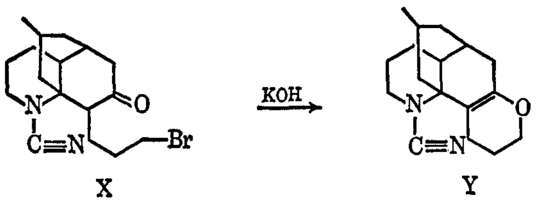
[2] J. Bredt, *Ann.*, **437**, 1 (1924); *cf.* F. S. Fawcett, *Chem. Rev.*, **47**, 219 (1950).

CHART I



Although such reactions with the ketones I and II have been studied, examination of the literature revealed some results that were difficult to explain.

Christol and Mousseron[3] treated the bromo ketone I with potassium *t*-butoxide and benzene and found only the spiro ketone V (70% yield), whereas McLean[4] and co-workers had run a similar reaction in the multiring system X using methanolic potassium hydroxide and reported a 98% yield of the enol ether Y. Mayer[5] treated the bromo ketone II with aqueous potassium hydroxide and obtained a 27% yield of the spiro ketone VIII and a 2–5% yield of the bridged bicyclic ketone VII, but did not find the enol ether IX.



X Y

The purpose of this communication is to show that the major product from the base-catalyzed intramolecular reaction of the bromo ketone I is the enol ether VI rather than the spiro ketone V. In addition we found formation of the enol ether IX along with the reported[5] ketones VII and VIII from base treatment of the bromo ketone II. For comparison, the intramolecular reaction of the keto tosylate III under similar conditions was also studied.

The bromo ketone I, when treated with potassium *t*-butoxide in benzene as described by Christol and Mousseron,[3] gave a crude oil which by vpc[6] consisted of two products. Chromatography afforded a 78% yield of the enol ether VI and a 7.8% yield of the spiro ketone V. The structure of the enol ether VI is indicated by its nmr, triplet with complex splitting centered at τ 6.18 signaling the presence of protons on a carbon adjacent to oxygen and broad absorption from τ 7.5–8.9; and its infrared, $\lambda_{\max}^{\mathrm{CCl_4}}$ 5.92 μ (enol ether). The infrared spectrum of the enol ether VI is essentially identical with the spectrum published by Christol and Mousseron[3] and attributed to the spiro ketone V. The structure of the authentic spiro ketone V isolated above was confirmed by its infrared, $\lambda_{\max}^{\mathrm{CCl_4}}$ 5.85 μ (C═O), and by combustion analysis of its 2,4-dinitrophenylhydrazone, mp 138–139°. The only other possible structure, the bridged ketone IV, has been prepared previously[7] and forms a 2,4-dinitrophenylhydrazone, mp 191–192°.

Treatment of the bromo ketone II in a similar manner with potassium *t*-butoxide in refluxing benzene gave upon work-up a crude liquid which by vpc[6] was a mixture of the enol ether IX, the spiro ketone VIII and the bridged ketone VII. This mixture was separated *via* distillation into two fractions. The lower boiling fraction was freed of ketonic material *via* reaction with sodium borohydride and afforded upon work-up and chromatography a pure sample of the enol ether IX: infrared, $\lambda_{\max}^{\mathrm{CCl_4}}$ 5.91 μ (enol ether); nmr, triplet centered at τ 6.07 (methylene protons on carbon adjacent to oxygen in a cyclic ether).

Treatment of the higher boiling fraction with acid afforded upon work-up and chromatography pure samples of the spiro ketone VIII and of the bridged ketone VII. The yields of these components as determined by quantitative vpc[6] were enol ether IX (22%), spiro ketone VIII (30%), and bridged ketone VII (19%). Reaction of the bromo ketone II with aqueous potassium hydroxide gave the same three products but in lower yields and slightly different

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[3] H. Christol, M. Mousseron, and F. Plenat, *Bull. Soc. Chim. France*, 543 (1959).

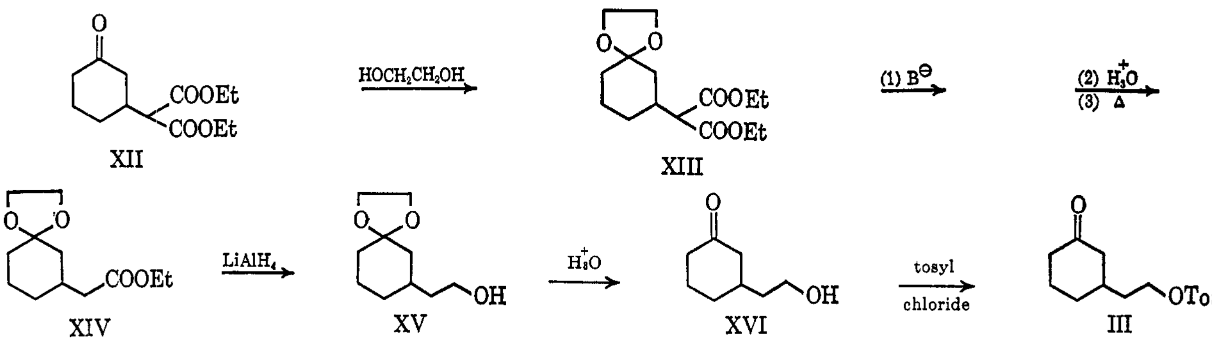
[4] D. B. McLean, W. R. Song, and W. A. Harrison, *Can. J. Chem.*, **38**, 528 (1960).

[5] R. Mayer, G. Wenschuh, and W. Topfelmann, *Chem. Ber.*, **91**, 1616 (1958).

[6] Vapor phase chromatographic work was done with an Aereograph Hi-Fi Model 600 with nitrogen at a flow rate of 20–30 m/min as the carrier gas on a 10-ft 20% Craig polyester column. The retention times when given are based on that of ether as 0.

[7] D. M. Bailey, H. E. Bowers, and C. D. Gutsche, *J. Org. Chem.*, **28**, 610 (1960).

CHART II



proportions, enol ether IX (15%), spiro ketone VIII (13%), and bridged ketone VII (6%).

These results indicate that all three possible products are formed in this case. In both reactions the route to enol ether formation involves a relatively strain-free six-membered transition state. Formation of the bridged ketones also involves a six-membered transition state, but an axial conformation of the side chain is required and considerable nonbonded interactions are built up in the transition state.

Treatment[8] of the keto tosylate III, prepared as shown in Chart II, with sodium hydride in dimethoxyethane gave upon work-up a semicrystalline oil which by vpc was at least 95% of the bridged ketone X. Sublimation afforded a pure sample of X.

This same cyclization product X, isolated as the 2,4-dinitrophenylhydrazone in 73% yield, was observed when III was treated with potassium *t*-butoxide in *t*-butyl alcohol. It is interesting that in this case no four-membered ring is formed.[9]

Experimental Section

Reaction of I with Potassium *t*-Butoxide[13] to Give 5,6,7,8-Tetrahydrochroman (VI) and Spiro[3.5]nonan-5-one (V).—To a magnetically stirred mixture of 1.232 g (0.011 mole) of potassium *t*-butoxide in 100 ml of dry benzene was added in a single portion 2.19 g (0.01 mole) of bromo ketone I (2,4-dinitrophenylhydrazone mp 86°; lit.[3] mp 86°). The resulting mixture was refluxed under nitrogen for 5 hr, cooled to room temperature, and poured into 50 ml of water. The layers were separated and the aqueous one was extracted with 3 × 30 ml of ether. The combined organic layers were washed with saturated brine, dried, and freed of solvent *via* distillation at atmospheric pressure through a 2.5-in. Vigreux column. The remaining colorless liquid, which by vpc[6] at 170° was found to be a mixture of the enol ether VI [rt (retention time): 4.4 min] and the spiro ketone V (rt: 8.1 min), was chromatographed on 40 g of Merck basic alumina.

Pentane[10] (200 ml) eluted 1.07 g (78%) of the enol ether VI. Distillation of the above material through a spinning-band column afforded an analytical sample of VI: bp 85° (25 mm), lit.[11] bp 80–83° (15 mm); infrared, $\lambda_{max}^{CCl_4}$ 5.92 μ (enol ether); nmr (neat), triplet with complex splitting centered at τ 6.18 (1.82 H), broad absorption from τ 7.5–8.9 (11.8 H).

Anal. Calcd for $C_9H_{16}O$: C, 78.21; H, 10.21. Found: C, 78.41; H, 10.30.

Elution with 10% ether-pentane (100 ml) gave 0.107 g (7.8%) of the spiro ketone V, a colorless liquid: infrared, $\lambda_{max}^{CCl_4}$ 5.85 μ (C=O).

2,4-Dinitrophenylhydrazone.—Spiro ketone V [(0.027 g (0.0002 mole)] afforded 0.050 g (80%) of crude orange 2,4-dinitrophenylhydrazone. Four recrystallizations from absolute ethanol afforded an analytical sample, mp 138–139°.

Anal. Calcd for $C_{15}H_{18}N_4O_4$: C, 56.59; H, 5.70. Found: C, 56.20; H, 5.49.

In a separate experiment using the same reagents and reaction conditions described above, the combined organic layers were dried and concentrated to a volume of 138 ml. Vapor phase chromatographic analysis using the column and conditions described before of a 10-ml aliquot of the above solution containing 0.086 g of *t*-butylcyclohexanone as an internal standard showed that the yield of enol ether VI in this reaction was 1.15 g (83%) and the yield of spiro ketone V was 0.138 g (10%).

Reaction of Bromo Ketone II with Potassium *t*-Butoxide.—To a refluxing mixture of 6.16 g (0.055 mole) of potassium *t*-butoxide in 500 ml of dry benzene was added dropwise with stirring over a period of 30 min, a solution of 10.25 g (0.05 mole) of the bromo ketone II (2,4-dinitrophenylhydrazone: mp 105–106°; lit.[3] mp 106°) in 50 ml of dry benzene. The resulting mixture was then heated under reflux for 5 hr.

Upon cooling, the mixture was added to 350 ml of water, the layers were separated, and the aqueous one was extracted with 3 × 100 ml of ether. The combined organic solutions were washed with 3 × 50 ml of saturated brine, dried, and freed of solvent *via* distillation at atmospheric pressure. The remaining oil was first distilled at 65–72° (17 mm) to afford 2.4 g of a colorless liquid. Subsequent distillation in a Hickman still of the residue afforded an additional 1.0 g of higher boiling liquid. Both distillation fractions were shown by vpc[6] at 150° to be mixtures of the enol ether IX (rt: 4.2 min), the spiro ketone VIII (rt: 6.7 min), and the bridged ketone VII (rt: 13.4 min).

Isolation of 1-Oxabicyclo[4.3.0]non-8(9)-ene (IX).—The 2.4-g fraction described above was stirred for 18 hr at room temperature with a mixture of 1.00 g (0.026 mole) of sodium borohydride in 35 ml of 95% ethanol.

The mixture was poured into 500 ml of water and the organic material extracted with 3 × 75 ml of ether. The combined ether extracts were washed with 40 ml of saturated brine, dried, and freed of solvent *via* atmospheric distillation through a short Vigreux column. The residual oil was chromatographed on 40 g of Merck basic alumina.

Hexane[10] (100 ml) eluted 0.55 g of enol ether IX, as a colorless liquid: infrared, $\lambda_{max}^{CCl_4}$ 5.91 μ (enol ether), and a small impurity peak at 5.76 μ (C=O); nmr (neat), triplet centered at τ 6.07 (1.8 H), large broad absorption from τ 7.2–8.6 (10 H).

2,4-Dinitrophenylhydrazone.—Orange crystals, mp 154–155° (EtOH), lit.[12] mp for the 2,4-dinitrophenylhydrazone of 3-(2 oxocyclopentyl)propanol 155–156°, were obtained.

Isolation of Spiro[3.4]octan-5-one (VIII) and Bicyclo[3.2.1]-octan-8-one (VII).—The 1.0 g of higher boiling material was stirred for 18 hr at room temperature with a mixture of 10 ml of 1 *N* hydrochloric acid solution and 10 ml of tetrahydrofuran.

The reaction mixture was poured into 100 ml of water and the organic material extracted with several portions of ether. The combined ether extracts were washed with saturated brine, dried, and freed of solvent *via* atmospheric distillation through a short Vigreux column. The remaining oil was chromatographed on 40 g of Merck basic alumina.

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[8] Subsequent to the completion of this work we learned of the use of this reaction in the total synthesis of *dl*-Atisine by W. Nagata, T. Sugasawa, M. Narisador, T. Wakabayashi, and Y. Hayase, *J. Am. Chem. Soc.*, **85**, 2342 (1963).

[9] This work was supported by National Institute of Health predoctoral research fellowship number 5-F1-GM-15,527-03.

[10] All chromatography fractions were freed of solvent *via* distillation at atmospheric pressure.

[11] I. J. Borowitz and G. Gonis, *Tetrahedron Letters*, **No. 19**, 1151 (1964).

[12] S. Fujise, H. Uda, T. Ishihowa, H. Obara, and A. Fujino, *Nippon Kagaku Zasshi*, **82**, 62 (1961).

Five per cent ether–hexane (100 ml) eluted 0.29 g of spiro ketone VII as a colorless liquid: infrared, $\lambda_{max}^{CCl_4}$ 5.75 μ (C=O); nmr (neat), complex undefined absorption, τ 7.5–8.6.

2,4-Dinitrophenylhydrazone.—Orange crystals, mp 166–167° (EtOH), lit.[5] mp 163–165°, were obtained.

Ten per cent ether–hexane (100 ml) eluted 0.198 g of the bridged ketone VII as a crude solid, which when sublimed at about 50° (20 mm) afforded white crystals: mp 133–136° (sealed tube), lit.[13] mp 134–136°.

2,2-Dinitrophenylhydrazone.—Orange needles, mp 174–175° (EtOH), lit.[5] mp 175–176°, were obtained.

A separate experiment executed initially as described above but using 1.026 g (0.005 mole) of the bromo ketone II, 0.616 g (0.0055 mole) of potassium *t*-butoxide, and 50 ml of dry benzene was run. The cooled reaction mixture was poured into 50 ml of water, the layers were separated, and the benzene one was washed with 3 × 30 ml of saturated brine and dried.

Vapor phase chromatographic[6] analysis of the above solution at 153° using camphor-*d* as an internal standard showed that this reaction had afforded 0.136 g (22%) of enol ether IX, 0.187 g (30%) of the spiro ketone VIII, and 0.119 g (19%) of the bridged ketone VII.

Reaction of II with Aqueous Potassium Hydroxide.—A mixture of 10 g (0.049 mole) of bromo ketone II and 40 ml of 35% aqueous potassium hydroxide was refluxed under nitrogen for 7 hr, cooled to room temperature, and extracted with 3 × 30 ml of ether. The combined ether extracts were washed to neutrality with saturated brine, dried, and diluted with ether to exactly 100 ml.

Vapor phase chromatography[6] at 165° of a 10-ml aliquot of this solution containing 0.174 g of camphor-*d* as an internal standard showed that this reaction had yielded 0.889 g (14.7%) of enol ether IX, 0.792 g (13%) of spiro ketone VIII, and 0.359 g (5.9%) of bridged ketone VII.

Bicyclo[2.2.2]octanone (X).—To a stirred suspension under nitrogen at room temperature of 0.24 g (0.010 mole) of sodium hydride in 35 ml of dry dimethoxyethane was added dropwise over a period of 20 min a solution of 1.48 g (0.005 mole) of keto tolsylate III in 5 ml of dry dimethoxyethane. The resulting mixture was heated under reflux for 7 hr.

Upon cooling, excess sodium hydride was destroyed with ethanol, the reaction mixture was poured into 500 ml of water, and organic material was extracted with 3 × 250 ml of ether. The combined ether extracts were washed with 2 × 200 ml of water plus 1 × 100 ml of saturated brine, dried, and freed of solvent. The residual oil was by vpc[6] at 171° at least 95% the desired bicyclo ketone X (rt: 6.2 min). There were four small peaks (rt: 1.9, 3.1, 3.4, and 5.4 min). The oil was sublimed at 50° (15 mm) and afforded X in 25% yield as a white solid: mp 145–171°. Resublimation afforded X as a white crystalline solid: mp 176–180°, lit.[14] mp 178–179°.

2,4-Dinitrophenylhydrazone.—Light orange crystals, mp 163.5–165° (EtOH), lit.[15] mp 166–167°, were obtained.

Reaction of III with Potassium *t*-Butoxide.—To a stirred solution at room temperature of 1.43 g (0.0048 mole) of keto tosylate III in 25 ml of dry *t*-butyl alcohol was added dropwise over a period of 5 min a solution of 0.561 g (0.005 mole) of potassium *t*-butoxide in 25 ml of dry *t*-butyl alcohol. The resulting mixture was refluxed for 2.5 hr, cooled, and poured into 500 ml of saturated brine. The organic material was extracted with 3 × 200 ml of ether. The combined ether layers were washed with saturated brine, dried, and freed of ether.

Of the remaining 38.82 g of *t*-butyl alcohol solution, a 9.7-g aliquot was refluxed for 10 min with a solution of 0.267 g (0.00135 mole) of 2,4-dinitrophenylhydrazine and 0.25 ml of concentrated sulfuric acid in 4 ml of methanol. Upon cooling, the precipitate was collected by filtration, washed with a small amount of cold ethanol, and, when dried, afforded 0.268 g (73%) of the 2,4-dinitrophenylhydrazone of X: mp 155–159°.

One recrystallization from ethanol, afforded orange crystals, mp 163–165°, which was not depressed when this material was admixed with an authentic sample (prepared above) of the 2,4-dinitrophenylhydrazone of X.

Synthesis of 2-(3-Oxocyclohexyl)ethyl Tosylate (III). Ethyl (3-Ethylenedioxycyclohexyl)acetate (XIV).—A solution of 424 g (1.66 moles) of ethyl (3-oxocyclohexyl)malonate (XII),[16] 106 ml (1.91 moles) of ethylene glycol, and 3.13 g (0.0164 mole) of *p*-toluenesulfonic acid in 1500 ml of dry benzene was refluxed under a water separator for 6 hr. The cooled reaction mixture was poured into 500 ml of water, the layers were separated, and the aqueous one was extracted with 250 ml of benzene; the combined benzene layers were washed with saturated brine, dried, and freed of solvent. There remained 497 g of the ketal diester XIII as a crude brown oil: nmr (carbon tetrachloride), quartet centered at τ 5.90, strong singlet at τ 6.18, small doublet centered at τ 6.91, broad absorption from τ 7.30 to 9.25 with a triplet centered at τ 8.76.

The crude ketal XIII (497 g) was added in a single portion under nitrogen to a room temperature solution of 110 g (1.67 moles) of potassium hydroxide (86% purity) in 3000 ml of absolute ethanol. After stirring for 1 hr at room temperature, the reaction was quenched by the addition of a solution of 20 ml of concentrated hydrochloric acid in 60 ml of water. After removal of most of the ethanol under reduced pressure, the residue was added to a mixture of 500 g of ice and 120 ml of concentrated hydrochloric acid and the product was extracted immediately with 2 × 250 ml of methylene chloride. The combined organic layers were washed to neutrality with saturated brine, dried, and freed of solvent. The residue was heated at 160° for 2.5 hr under reduced pressure and then distilled at 129–140° (0.5 mm) affording 225 g (59.5%) of the ketal ester XIV.

The distillation residue (145 g) was stirred for 3 hr with a solution of 31.6 g (0.485 mole) of potassium hydroxide (86% purity) in 800 ml of absolute ethanol. When worked up and distilled as described above, it afforded an additional 53 g (14.0%) of the ketal ester XIV: nmr (carbon tetrachloride), quartet centered at τ 5.92 and a singlet at τ 6.14 (6.0 H), complex absorption τ 7.7–9.1 in which a triplet at τ 8.80 could be distinguished (14 H).

Anal. Calcd for $C_{12}H_{20}O_4$: C, 63.13; H, 8.83. Found: C, 63.15; H, 8.68.

2-(3-Ethylenedioxycyclohexyl)ethanol (XV).—To a mechanically agitated suspension of 28.4 g (0.75 mole) of lithium aluminum hydride in 800 ml of anhydrous ether was added dropwise, at a rate designed to maintain gentle reflux, a solution of 115 g (0.505 mole) of ketal ester XIV in 100 ml of anhydrous ether. The reaction mixture was stirred at room temperature for an additional 22 hr. Unreacted lithium aluminum hydride was destroyed by the slow addition of saturated sodium sulfate solution, excess solid sodium sulfate was added, and the ether layer was decanted. The salts were slurried with 200-ml portions of ether until they no longer extracted organic material. The combined ether solutions were dried and freed of solvent. In a like manner was reduced an additional 105 g (0.46 mole) of ketal ester XIV.

The residues from both experiments were combined and distilled at 110° (0.15 mm) affording 129 g (72%) of the colorless liquid XV: infrared, $\lambda_{max}^{CHCl_3}$ 2.77 and 2.92 μ (O–H); nmr (chloroform), small singlet at τ 5.91, large singlet at τ 6.13, triplet centered at τ 6.42, and broad absorption from τ 7.5 to 9.1.

Anal. Calcd for $C_{10}H_{18}O_3$: C, 64.49; H, 9.74. Found: C, 64.49; H, 9.66.

2-(3-Oxocyclohexyl)ethanol (XVI).—To the ketal alcohol XV [70 g (0.376 mole)] dissolved in 900 ml of methanol was added 28 ml of 10% perchloric acid solution. After standing at room temperature for 1.5 hr, the reaction mixture was neutralized with saturated sodium bicarbonate solution and freed of methanol by flash evaporation at the water pump. The residue was poured into 75 ml of water; the organic material was extracted with 3 × 100 ml of methylene chloride. Extracts were washed with saturated brine, dried, and freed of solvent. The residue distilled at 137° (0.5 mm) affording 32.2 g (60%) of a colorless liquid which by nmr was about 90% the desired keto alcohol XVI: infrared, $\lambda_{max}^{CHCl_3}$ 2.9 (O–H) and 5.86 μ (C=O); nmr (carbon tetrachloride), broad singlet at τ 5.82 (1 H), small sharp singlet at τ 6.14 (0.27 H) (contaminent), quartet centered at τ 6.42 (2 H), and broad absorption from τ 7.28–9.30 (10.5 H). This material was found to be of sufficient purity for further reaction.

2-(3-Oxocyclohexyl)ethyl Tosylate (III).—To a stirred solution of 5.68 g (0.04 mole) of keto alcohol XVI in 65 ml of dry pyridine at −5° was added in several portions 9.52 g (0.05 mole) of recrystallized *p*-toluenesulfonyl chloride. The reaction mixture was allowed to stand at 0° for 18 hr. The excess *p*-toluenesulfonyl

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[15] H. M. Walborsky and D. F. Loncrini, *J. Am. Chem. Soc.*, **76**, 5398 (1954).

[16] Synthesized by the procedure of P. D. Bartlett and G. F. Woods, *ibid.*, **62**, 2933 (1940).

chloride was hydrolyzed by adding 30 ml of ice-cold 5% sodium bicarbonate solution and stirring for 10 min at 0°. The resulting mixture was then poured into 500 ml of ice-cold 1 *N* hydrochloric acid solution and the product was extracted immediately with 1 × 500 plus 2 × 200 ml of ether. The combined ether extracts were washed with 1 × 100 ml of water and 2 × 100 ml of saturated brine, dried, and freed of solvent. The residual oil (11.45 g) when crystallized from ether–hexane afforded 8.0 g (67%) of crystalline keto tosylate III, mp 49–50°.

Two more recrystallizations from ether–hexane afforded an analytical sample of III, white crystals: mp 51–52°; infrared, $\lambda_{\max}^{\mathrm{CHCl_3}}$ 5.85 (C=O) and 7.3 and 8.4 μ (tosyl ester).

Anal. Calcd for $C_{15}H_{20}O_4S$: C, 60.78; H, 6.80. Found: C, 61.05; H, 6.89.

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The Reaction of α-Substituted Toluenes with N-Bromosuccinimide[1]

Glen A. Russell and Yvette R. Vinson

Department of Chemistry, Iowa State University, Ames, Iowa 50010

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Lovins, Andrews, and Keefer in 1964 reported enhanced reactivity (relative to toluene) in N-bromosuccinimide (NBS) bromination of toluenes with electron-supplying (methoxy, phenoxy, and thiophenoxy) and with certain electron-withdrawing (chloro, nitro, and acetoxy) α substituents.[2] The results were so in discord with current beliefs with regard to polar effects in free-radical reactions,[3] including the effect of *meta* and *para* substituents on the bromination of toluenes by bromine or NBS,[4] or with regard to the effects of α substituents on reactivities of carbon–hydrogen bonds in reactions in which polar effects are not important,[5] that we decided to repeat this work employing techniques developed previously.[6] While the work was in progress Lovins, Andrews, and Keefer corrected some results reported in their 1964 paper.[7] Table I summarizes the data originally reported by Lovins, Andrews, and Keefer (column 2). Their revised reactivities[7] are given in parentheses in column 2. Our results as summarized in column 3 show discrepancies with both the original and revised data of Lovins, Andrews, and Keefer, but the agreement with the revised numbers is much better than with their original report. We find no evidence that a strong electron-withdrawing group (−I), that cannot supply electrons by a resonance interaction (+R), activates the benzylic hydrogen atoms of an α-substituted toluene to attack by the bromine atom.[8] This is in accord with the accepted theories of polar effects in free-radical processes.

The competitive brominations were all relative to toluene and are summarized in Table II.

TABLE I

RELATIVE REACTIVITIES OF BENZYLIC-TYPE HYDROGEN ATOMS OF $C_6H_5CH_2X$ IN BROMINATION WITH NBS

X	CCl_4, 77°[a]	CH_2Cl_2, 40°[b]
CN	0.64 (0.13)	0.56
CO_2CH_3	0.87 (0.23)	0.042 ± 0.002
NO_2	2.8 0.104[b]	0.052 ± 0.003
Cl	4.2 (0.31)	0.24 ± 0.02
H	1.00	1.00
$OCOCH_3$	2.4	1.08 ± 0.04
CH_3	14	21 ± 2[c]
C_6H_5	18 (10)	10 ± 1.5[c]

[a] Data from ref 2 and, in parenthesis, ref 7. [b] Present work. [c] Reference 6.

TABLE II

COMPETITIVE BROMINATION OF TOLUENE AND α-SUBSTITUTED TOLUENES BY NBS AT 40° IN METHYLENE CHLORIDE SOLUTION[a]

α substituent	$[A]_o$[b]	$[A]_f$[b]	$[B]_o$[c]	$[B]_f$[c]	k_A/k_B[d]
Cl	1.00	0.739	1.00	0.257	0.171
Cl	1.00	0.831	1.00	0.240	0.130
Cl	1.02	0.797	1.00	0.227	0.153
Cl	2.0	1.55	1.00	0.225	0.171
NO_2	0.989	0.910	0.990	0.084	0.034
NO_2	0.989	0.915	0.990	0.082	0.032
NO_2	1.00	0.920	1.01	0.106	0.037
CN	1.00	0.572	1.00	0.098	0.241
CN	1.00	0.460	1.00	0.085	0.505
CN[e]	1.01	0.476	3.00	0.573	0.452
CN[e]	1.01	0.440	3.00	0.535	0.480
CN	0.500	0.223	1.00	0.147	0.398
$COOCH_3$	1.00	0.953	1.01	0.189	0.029
$COOCH_3$	1.01	0.966	1.01	0.187	0.027
$OCOCH_3$	1.00	0.599	1.00	0.505	0.751
$OCOCH_3$	1.01	0.646	1.01	0.533	0.696
$OCOCH_3$	1.01	0.623	1.00	0.514	0.724
NO_2[f]	1.00	0.869	1.00	0.146	0.073
NO_2[f]	1.00	0.876	1.00	0.140	0.068
NO_2[f]	1.01	0.886	1.00	0.136	0.066

[a] Solutions of 20-ml volume at 25° were employed. [b] Substituted toluene. [c] Toluene. [d] Per molecule, calculated by the equation $k_A/k_B = \log([A]_f/[A]_o)/\log([B]_f/[B]_o)$. [e] Solutions of 10-ml. volume. [f] Carbon tetrachloride at 77°.

Our results with phenylacetonitrile were not reproducible and suggest that possibly the nitrile was in part consumed by some other reaction, perhaps the addition of an acidic material to the nitrile group. With benzyl acetate and dibenzyl ether we found by gas–liquid partition chromatography (glpc) the presence of two substances indicative of molecular cleavage, since they were eluted prior to benzyl acetate. These substances were not formed with any of the other substrates. The most important of these substances was identified as benzaldehyde, presumably found by the following reaction.[9] If R· is not trapped by

$$C_6H_5\dot{C}HOR \longrightarrow C_6H_5CHO + R\cdot$$
$$R = CH_3CO,\ C_6H_5CH_2$$

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[8] Evidence that bromination by NBS involves attack by a bromine atom has been presented in ref 4 and 6.

[9] For additional examples of this process, see R. L. Huang, H. H. Lee, and S. H. Ong, *J. Chem. Soc.*, 3336 (1962).