

PHOTOCHEMICAL SYNTHESSES

6. THE FORMATION OF HEPTANDIONES FROM ACETYLACETONE AND ALKENES¹

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ABSTRACT

The irradiation of acetylacetone in the presence of oct-1-ene, cyclopentene, cyclohexene, and 1-methylcyclohexene gives substituted heptandiones. These diketones may then be cyclized with acid or base. Irradiation of isopropenyl acetate and acetylacetone gives, after cyclization, *m*-5-xyleneol. The mechanism of the reaction is discussed: it represents the first cycloaddition to an isolated ethylenic linkage.

Saturated ketones have absorption bands in the ultraviolet at about 280 m μ . This band is associated with an $n \rightarrow \pi^*$ transition of a non-bonded electron on the oxygen atom into an anti-bonding π -orbital (2): α, β -unsaturated ketones have a similar band at somewhat longer wavelength. Such excitation of saturated ketones in condensed phases leads to a number of transformations which follow on the formation of the original excited species. Amongst these are cyclobutanol formation and fission between the α - and β -carbon atoms: both these processes are initiated by γ -hydrogen abstraction by the electron-deficient oxygen atom.²

In the presence of substrates which may give stabilized radicals by hydrogen abstraction another course may be followed, particularly when there is no such γ -hydrogen available for intramolecular abstraction. The activated ketone, most probably as the triplet (4, and references cited therein), is converted into the ketyl, which then, in turn, may react with another ketyl or with some other radical derived from the substrate (see, for instance, refs. 5, 6, 7).

The irradiation of acyclic α -diketones also appears to conform to this general pattern. In the absence of a reactive substrate cyclobutanol formation proceeds in high yield (8), whilst in the presence of benzylic (9) or allylic hydrogen (10) alkylation is observed.

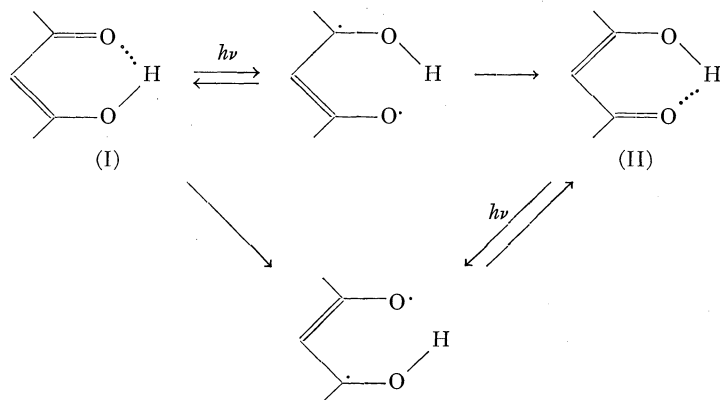
The irradiation of β -diketones, on the other hand, does not appear to have been studied up to the present. Acetylacetone, the simplest readily available acyclic β -diketone, exists in solution in hydrocarbons largely in the enolic form (I) (11). In this system γ -hydrogen abstraction is, presumably, strongly favored following $n \rightarrow \pi^*$ excitation, because of the proximity of that hydrogen atom. However, in this special case the ketyl so formed is readily transformed into (II), the tautomer of (I), and differing from it at most in small internuclear distances.³ Hydrogen abstraction from the solvent may thus be expected to be slow and might not occur provided some other mode of chemical behavior were available to the excited diketone molecule.

Irradiation of acetylacetone in cyclohexene induced a reaction which could be followed by the disappearance of the enol bands at about 6.3 μ . The product, obtained in high yield, appeared homogeneous to gas-liquid chromatographic (g.l.c.) analysis and, significantly, no trace of bicyclohexenyl could be detected. The latter is an inevitable

¹Part of the material contained herein formed a preliminary communication (1).

²For a review of these and other transformations following $n \rightarrow \pi^*$ excitation see reference 3.

³In the present instance the tautomers are identical, but with other unsymmetrical β -diketones capable of chelation the more general statement applies.



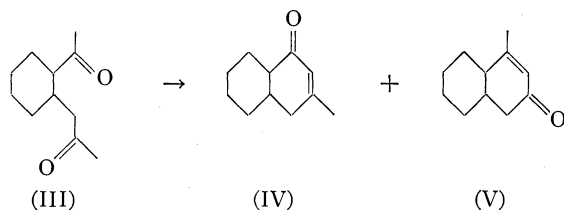
by-product of radical reactions in cyclohexene and in these circumstances its absence could be taken as an encouraging indication of the absence of such processes.

That an $n \rightarrow \pi^*$ excitation was most probably responsible for the observed transformation was established by repeating the irradiation using a pyrex filter. This resulted in a decrease in yield of only one third, whilst under these conditions essentially all the light responsible for $\pi \rightarrow \pi^*$ excitation was cut out.

The product analyzed for a 1:1 adduct of cyclohexene and acetylacetone. It showed no high-intensity absorption in the ultraviolet, had a band in the infrared at 1717 cm^{-1} compatible with saturated ketones, and gave a crystalline dioxime. The n.m.r. spectrum showed the presence of a singlet (6 H) at τ 8.0, suggesting (ref. 12, p. 57) the presence of two acetyl groups, and there was no indication of vinyl hydrogen. Treatment of the diketone with acid led, with the loss of one molecule of water, to the formation of two isomeric unsaturated ketones, characterized as the 2:4-dinitrophenylhydrazones.

Both unsaturated ketones showed, in the n.m.r. spectra, the presence of allylic methyl (singlet, 3 H, τ 8.09) and of one vinyl hydrogen (at τ 4.30, singlet). The infrared spectra (bands at 1674 and 1675 cm^{-1} respectively) suggested the presence of cyclohexenones and hence the formulation of (III), (IV), and (V) for the diketone and the unsaturated ketones respectively.

A distinction between (IV) and (V) was also possible from the infrared spectra. That assigned the structure (V) showed a band at 1415 cm^{-1} attributed to the deformation vibrations of methylene α to the carbonyl (ref. 13, p. 22) whilst that assigned the structure (IV) showed a band at somewhat higher wave numbers (1423 cm^{-1}) attributed to the

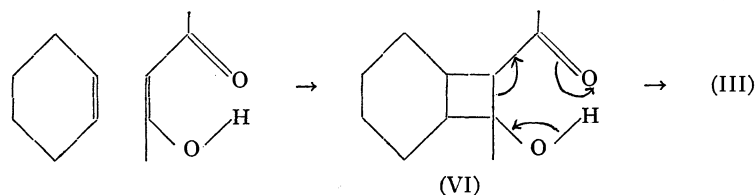


allylic methylene group (ref. 13, p. 23). The assignments were confirmed in the present instance⁴ by reduction of the ketones with sodium borohydride followed by dehydrogena-

⁴The formation of (IV) had been previously reported by Barrett, Cook, and Linstead (14) as being formed by the condensation of acetylcyclohexene and sodioacetoacetate. Repetition of the preparation showed, however, that here also the product was a mixture of (IV) and (V).

tion over palladized charcoal. This treatment gave β - and α -methylnaphthalene respectively, which were characterized as the picrates and compared with authentic specimens.

The formation of (III) most probably proceeds through the cyclobutane derivative (VI). The formation of cyclobutane derivatives by the dimerization of unsaturated ketones is well known (15) and the intramolecular addition of an ethylenic linkage to an unsaturated ketone has already been observed (16).⁵ The present reaction constitutes the first intermolecular addition to an isolated ethylenic linkage. In support of this view the infrared spectrum of the crude irradiation product showed strong hydroxyl absorption which disappeared on slight warming. These conditions define the stability

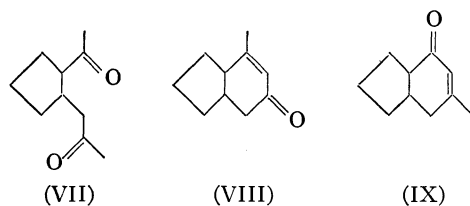


of the β -hydroxyketone since the dealdolization may be a purely thermal process (VI, see arrows).

If the mechanism proposed is correct the diketone (III) as originally formed should be cis. Although trans fusions of six- and four-membered rings do occur, and have been prepared recently in the ring D norsteroids (18(a)), it seems probable though not mandatory that the lower-energy pathway should be selected here (18(b)). However, since the stable configuration of the diketone is trans (both substituents equatorial) it is not impossible that complete or partial inversion may have occurred during distillation. Further equilibration was not attempted since, in general, such conditions are those that lead to cyclization.

Cyclization, irrespective of the stereochemical homogeneity of the starting material, could lead to both cis and trans isomers. The two ketones obtained, (IV) and (V), appeared homogeneous to g.l.c. on several columns, but this criterion must be accepted with reserve since the same was true of a derivative from 1-methylcyclohexene (see below), and this was shown to be a mixture.

Similar irradiation of acetylacetone with cyclopentene gave the expected diketone (VII), characterized as the dioxime. Cyclization with base then gave the ketones (VIII) and (IX), characterized as the 2:4-dinitrophenylhydrazones. The assignment of structure was made on the basis of the methylene deformation frequencies which occurred at the same position as in the cyclohexene series.

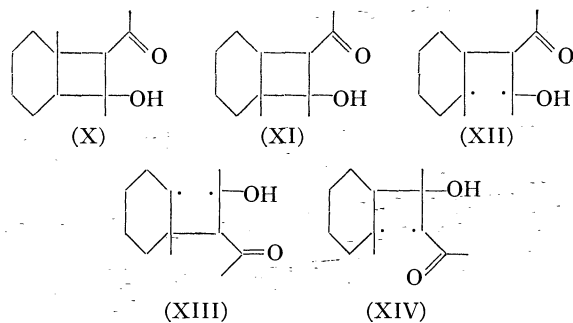


In those natural products in the alicyclic series in which this present approach might be of synthetic utility a common structural feature is that of an angular methyl group.

⁵The intermolecular addition of alkenes to unsaturated acids has been observed in these laboratories and will be reported shortly (17). The addition of cyclopentenone to cyclopentene has since been reported by Eaton (27).

Although the introduction of this feature might be achieved by methylation, an alternative route could be the use of methylcyclohexene as a substrate. Addition of acetylacetone to such an unsymmetrically substituted ethylenic linkage could proceed to give either of the two compounds (X) or (XI). Assuming that the addition is not entirely concerted,⁶ then the addition should proceed to give the more stable intermediate biradical. This appears to be the case, for instance, in the related addition of carbonyl groups to methylbut-2-ene to give oxetanes (20; 28; 3, p. 379). In that instance it is the oxygen atom (which is electron deficient because of electron promotion) which attacks the π -bond. In the present case if the α -carbon be presumed to be electron deficient the predicted more stable diradical⁷ would be (XII) rather than (XIII). Little analogy can be made with the dimerization of unsaturated ketones (in which, presumably, one molecule of the forming dimer is activated) because of the influence of the phase in which the irradiation is done, and the uncertainty as to whether $n \rightarrow \pi^*$ or $\pi \rightarrow \pi^*$ excitation is involved in any particular example.⁸

To form the second carbon-carbon bond two opposed steric interactions (methylene and methyl vis-à-vis methyl and hydroxyl) must be overcome. Since, until this final bond formation, the processes are reversible this interaction might be a factor which could depress the rate of (XI) formation as against that of (X). In addition, with sufficient suppression or if the charge separation is small it is conceivable that the radical (XIV), which is more stable still, may be involved, although XIV would be formed from attack of the carbon β to the carbonyl, which may be unfavorable.



Irradiation of methylcyclohexene and acetylacetone led, in this event, to the formation of more than one product, as indicated by g.l.c. analysis, but at the temperature required for preparative separation extensive decomposition occurred together with the formation of cyclized products. The major component (50%) could, however, be isolated by fractional distillation. The remainder appeared to consist of three products one of which accounted for 20–30% of the original material. Its infrared spectrum indicated that it was a diketone but the best specimens were always contaminated with small amounts of cyclized products.

The major product was assigned the structure (XV) for the following reasons. It analyzes correctly, gave a crystalline dioxime, and showed a band in the infrared at 1709 cm^{-1} . Cyclization of (XV) with base gave two unsaturated ketones in the ratio

⁶The formation of other four-membered rings has also been suggested to be non-concerted (e.g. ref. 19). Recently, results on the dimerization of cyclopentenone have been interpreted (27) to imply either concertion or the lack of effect of stabilizing factors on intermediate species, presumably because of their high energy.

⁷Even if the addition has ionic character the same consequence follows since attack of ethylenes is electrophilic.

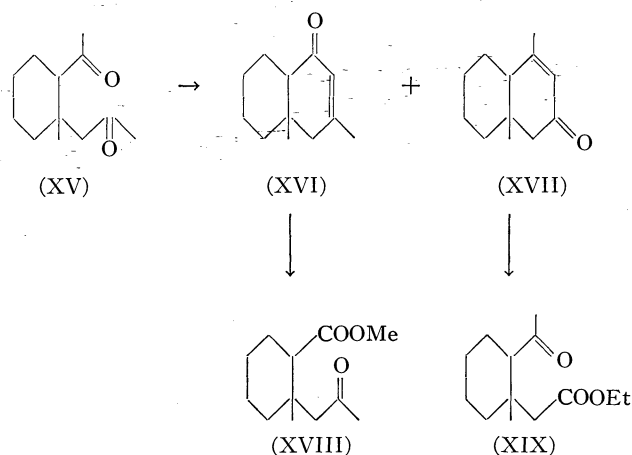
⁸Thus benzalacetophenone in solution gives head-to-tail union (21), whilst cholestenone gives head-to-tail (22). In coumarin (21) it is more probable that $\pi \rightarrow \pi^*$ activation is involved.

of 4:1 separable by g.l.c. The major product, (XVI), and the minor product, (XVII), both showed singlets (3 H) for the allylic methyl groups (at τ 8.16 and 8.02) (ref. 12, p. 58) and singlets at (τ 4.31 and 4.34) for one vinyl hydrogen, respectively. The compounds showed, again, the appropriate methylene deformation bands in the infrared. From this evidence it was not possible to distinguish between (XVI) and (XVII) on the one hand and the other two isomers bearing the angular methyl group at the alternative quaternary position on the other.

The unsaturated ketones were, therefore, ozonized to the keto acids, which were converted directly to the esters with diazomethane. The keto ester from (XVI) on g.l.c. was separable into two components characterized as the 2:4-dinitrophenylhydrazones. One, giving a dinitrophenylhydrazone, of m.p. 123–124°, showed a non-equivalent quartet (from the methylene group adjacent to the ketone) at 7.43 and 7.84 ($J \sim 15$ c.p.s.) (see ref. 12, p. 85). The other, giving a dinitrophenylhydrazone of m.p. 118–ca. 119°, showed a singlet (2 H) at τ 7.44. These keto esters are, therefore, the stereoisomers of (XVIII). The presence of a hydrogen atom at the bridgehead adjacent to the methylene group discussed above would, of course, have led to more complex splitting.

The same observations were made on the 2:4-dinitrophenylhydrazones, that of m.p. 123–124° showing a singlet (2 H) at τ 7.31, the other showing a non-equivalent quartet at τ 7.31, 7.47 ($J \sim 15$ c.p.s.).

The keto ester from (XVII) was homogeneous and also showed a non-equivalent quartet (at ca. τ 7.35, 7.95), in this case partly obscured by a multiplet (see below), again requiring that there be no hydrogen vicinal to the methylene group. In addition, all keto esters showed a multiplet at ca. τ 7.3–7.4 to be attributed to the methine hydrogen next to carbonyl. Other features of the n.m.r. spectrum were in accord with expectation.



The obtention of two keto esters from (XVI) may indicate that although no resolution could be obtained on the columns available (XVI) is a mixture of *cis* and *trans* forms. These may differ only slightly in energy (as do certain related decalones (24)). The same may be true of (XVII) also, but epimerization α to the ketone may have taken place after ozonolysis. Such epimerization is, of course, more likely to occur than that α to an ester.

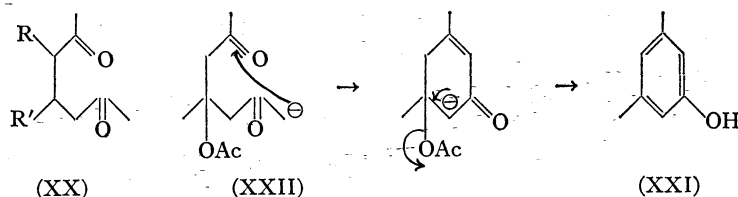
The nature of the other irradiation products can only be inferred since they were

not obtained pure, but it seems reasonable, on the basis of the spectral data, to assume that the minor product was, as in the case of oct-1-ene (see below), the isomeric diketone. The formation of *both* diketones is consonant with the concept that steric and electronic factors were opposed, and, indeed, the introduction of the extra methyl group slowed the photochemical addition considerably over that to the simple cycloalkene. Alternative interpretations (see, for instance ref. 27) are, however, presently possible and are under investigation. However, it appears that if a two-step mechanism is involved more than one of the diradicals (XII), (XIII), or (XIV) is concerned, and to a significant extent.

A similar situation with regards asymmetry obtains in oct-1-ene. Irradiation again led to the formation of the two possible diketones. Separation by g.l.c. was difficult because of condensation and decomposition, but pure specimens were obtained by the removal of unsaturated impurities from the chromatographed products by ozonolysis. The structures (XX; R = H, R' = C₆H₁₃) and (XX, R = C₆H₁₃, R' = H) were allocated by means of the n.m.r. spectrum. The latter showed a single peak (6 H) at τ 7.94 for the two acetyl groups since they are identically situated, whereas the former showed two closely placed singlets at τ 7.95 and 7.96.

The unsaturated ketonic products from these cyclizations are one double-bond equivalent distant from phenols. The incorporation of a potential double-bond equivalent into the substrate seemed possible using a suitably substituted double bond. This was attempted using isopropenyl acetate.

The irradiation of isopropenyl acetate with acetylacetone in cyclohexane gave a mixture of ketones the separation of which was not attempted. Direct cyclization of the mixture with base and isolation of the acidic material gave *m*-5-xenol (XXI), through (XXII), identified by melting point, comparison of the infrared spectrum with that published (25), and conversion into the known tribromide (26).



The nature of the products obtained in these irradiations, together with the absence of bicyclohexenyl, appears to indicate that the only reaction is the addition to the ethylenic linkage of the enol. In agreement with the foregoing discussion with regards activation and γ -hydrogen transfer, preliminary results in these laboratories indicate that β -keto esters and cyclic β -diketones behave differently.

EXPERIMENTAL

Materials were reagent grade and were dried over magnesium sulphate and distilled before use. Cyclohexene and cyclopentene were purified by shaking with aqueous ferrous sulphate, dried, and distilled. Oct-1-ene and 1-methylcyclohexene were refluxed over sodium wire and distilled. Before use the hydrocarbons, which were homogeneous to g.l.c. analysis, were filtered through a column of alumina. Nuclear magnetic resonance spectra were recorded on a Varian D.P. 60 instrument. Liquids were run in CCl₄ solution, solids in CDCl₃. Irradiations were performed under nitrogen in a water-cooled immersion apparatus using the power of lamp specified. Yields are based on acetylacetone and are not maximal. Ultraviolet spectra were determined in methanolic solution.

The Irradiation of Acetylacetone with Cyclohexene (with A. B. M. A. Sattar)

A solution of the diketone (15.02 g) in cyclohexene (135 ml) was irradiated with an 80-w lamp for 45 hours. After removal of the solvent the product was fractionated on a 40-in. spinning band column to give

the adduct, b.p. 89° at 1.7 mm, n_D^{25} 1.4691 (20.2 g; 78%). Calc. for $C_{11}H_{13}O_2$: C, 72.49; H, 9.91%. Found: C, 72.13; H, 9.62%.

The oxime (hydroxylamine hydrochloride - pyridine at room temperature), crystallized from methanol, had m.p. 165.5-167.5°. Calc. for $C_{11}H_{20}O_2N_2$: C, 62.23; H, 9.50; N, 13.20%. Found: C, 62.45; H, 9.34; N, 12.90%.

Acid-catalyzed Cyclization of the Cyclohexene Adduct (with A. B. M. A. Sattar)

A solution of the adduct (4.5 g) in ethanol (45 ml) was heated at 80° for 80 minutes with conc. hydrochloric acid (2 ml). After removal of the solvent the product was isolated with chloroform, the chloroform solution washed and dried (Na_2SO_4), and the solvent evaporated. Distillation (b.p. 173-175 at 1.5 mm) gave a mixture (5:3) of two unsaturated ketones (4.04 g; 95%). These were separated by chromatography over a 5-ft silicone SE 30 column at 200°, the separated fractions then being distilled at 180° (bath temp.) at 35 mm to give the following ketones.

(a) The unsaturated ketone (IV), n_D^{25} 1.5091, λ_{max} 231 m μ (ϵ , 19,400), ν_{max} 1675, 1637, 1423 cm^{-1} . Calc. for $C_{11}H_{16}O$: C, 80.18; H, 9.73%. The 2:4-dinitrophenylhydrazone, crystallized from ethyl acetate, had m.p. 201-202°, λ_{max} 380 m μ (ϵ , 24,000). Calc. for $C_{17}H_{20}O_4N_4$: C, 59.29; H, 5.85; N, 16.27%. Found: C, 59.29; H, 5.82; N, 16.31%.

(b) The unsaturated ketone (V), n_D^{25} 1.5160, λ_{max} 237 m μ (ϵ , 18,500), ν_{max} 1674, 1623, 1415 cm^{-1} . Calc. for $C_{11}H_{16}O$: C, 80.44; H, 9.83%. Found: C, 80.30; H, 9.75%. The 2:4-dinitrophenylhydrazone, crystallized from ethyl acetate, had m.p. 157-158°, λ_{max} 380 m μ (ϵ , 27,100). Calc. for $C_{17}H_{20}O_4N_4$: C, 59.29; H, 5.85; N, 16.27%. Found: C, 59.57; H, 5.85; N, 16.40%.

Dehydrogenation of Ketone (IV)

The ketone (200 mg) in methanol (10 ml) was added to a solution of sodium borohydride (55 mg) in methanol (3 ml) and water (2 ml) containing a trace of sodium hydroxide (1.0 N; 0.02 ml), and the mixture allowed to stand overnight. After acidification with acetic acid the product was isolated with ether and heated at 310° for 12 hours under nitrogen with palladized charcoal (10%; 200 mg). After cooling the charcoal was extracted with ether, and the residue obtained after evaporation of the solvent was treated with saturated alcoholic picric acid (1.5 ml). The picrate (85 mg, m.p. 108-110°) was recrystallized from ethanol to give β -methyl-naphthalene picrate, m.p. 114-115° undepressed on admixture with an authentic specimen of the same melting point. The hydrocarbon obtained on regeneration from the picrate had m.p. 31-32° and was undepressed on admixture with an authentic specimen of β -methyl-naphthalene of the same melting point. The infrared spectra were identical both in CS_2 and CCl_4 solution.

Dehydrogenation of Ketone (V)

The ketone (200 mg) was reduced in a manner identical with that described above for ketone (IV). Dehydrogenation with palladized charcoal in like manner and treatment of the product with saturated ethanolic picric acid gave the picrate (115 mg), which on crystallization from ethanol had m.p. 139°, undepressed on admixture with an authentic specimen of α -methyl-naphthalene of the same melting point. The infrared spectrum of regenerated hydrocarbon was identical with that of an authentic specimen of α -methyl-naphthalene in CS_2 and CCl_4 solution.

The Synthesis of Ketones (IV) and (V)

An ethanolic solution of sodioethylacetoacetate (from ethylacetoacetate (2.7 g) and sodium (0.25 g)) and acetylcyclohexene (25 g) was heated on a steam bath at 95° for 6 hours. After dilution with water the product was isolated with benzene. The distillation (149-158° at 3 mm) residue gave the ester mixture (890 mg); no trace of decarboxylated product could be detected by g.l.c. The keto ester (890 mg) was hydrolyzed by refluxing in ethanol (1.5 ml) containing sodium hydroxide (50 mg) and water (0.4 ml) for 3 hours. Extraction of the mixture with ether after dilution with water gave a yellow oil (790 mg). Separation of this by g.l.c. on a silicone Se 30 column at 200° gave ketones (IV) and (V) (1:4) identical in retention times and infrared spectra with the previously described specimens.

Further Irradiations of Cyclohexene and Acetylacetone

(a) Cyclohexene (2.4 g) and acetylacetone (11.0 g) in cyclohexane (190 ml) were irradiated with a 350-w lamp for 14 hours. Isolation of the product as described previously gave 2.4 g of material identical in infrared spectra and g.l.c. behavior (diethylene glycol succinate \equiv DEGS column) with that prepared under non-diluted conditions.

(b) Cyclohexene (0.82 g) and acetylacetone (1.0 g) were diluted to 190 ml with cyclohexane and irradiated with a 350-w lamp for 5 hours. Material, 1.35 g, identical with the above was obtained.

(c) Acetylacetone (20 g) in cyclohexene (135 ml) was irradiated with an 80-w lamp for 15 hours. Gas-liquid chromatographic analysis indicated that 12.3 g (33.2%) of adduct was formed. In an otherwise identical experiment using a pyrex jacket for the lamp 7.09 g (19.2%) of product was obtained identical in infrared spectrum and g.l.c. retention time with the product from unfiltered light.

Irradiation of Cyclopentene and Acetylacetone

A mixture of cyclopentene (130 g) and acetylacetone (15 g) was irradiated with an 80-w lamp for 95

hours. Removal of the excess cyclopentene by distillation gave a residue of 26 g. This was fractionated by distillation through a 40-in. spinning band column to give the diketone (VII) (17 g), b.p. 129° at 22 mm, n_D^{25} 1.4647, ν_{\max} 1712 cm^{-1} . Calc. for $\text{C}_{10}\text{H}_{16}\text{O}_2$: C, 71.39; H, 9.59%. Found: C, 71.76; H, 9.86%.

The oxime (hydroxylamine hydrochloride - pyridine at room temperature), crystallized from ethanol, had m.p. 138-139°. Calc. for $\text{C}_{10}\text{H}_{18}\text{O}_2\text{N}_2$: C, 60.58; H, 9.15; N, 14.13%. Found: C, 60.90; H, 9.21; N, 14.09%.

Base-catalyzed Cyclization of Cyclopentene Adduct

A solution of the diketone (VII) in methanol (100 ml) containing sodium hydroxide (50 mg; 1.2 ml water) was refluxed for 1 hour. The mixture was then neutralized with carbon dioxide, concentrated to about one-third volume under reduced pressure, and the product isolated with benzene. Distillation of the residue after evaporation of the benzene at 125° (bath temp.) at 0.4 mm gave an oil (0.76 g) consisting of two components in the ratio 3:2. These could be separated by g.l.c. on a 10-ft DEGS column at 175° to give the following ketones.

(a) The unsaturated ketone (VIII), n_D^{25} 1.5140, λ_{\max} 236 $\text{m}\mu$ (ϵ , 19,100), ν_{\max} 1673, 1636, 1418 cm^{-1} . Calc. for $\text{C}_{10}\text{H}_{14}\text{O}$: C, 79.95; H, 9.39%. Found: C, 79.57; H, 9.12%. The 2:4-dinitrophenylhydrazone, crystallized from methanol, had m.p. 174-175°, λ_{\max} 382 $\text{m}\mu$ (ϵ , 25,000). Calc. for $\text{C}_{16}\text{H}_{18}\text{O}_4\text{N}_4$: C, 58.17; H, 5.49; N, 16.96%. Found: C, 58.24; H, 5.36; N, 17.25%.

(b) The unsaturated ketone (IX), n_D^{25} 1.5153, λ_{\max} 233 $\text{m}\mu$ (ϵ , 16,100), ν_{\max} 1669, 1640, 1425 cm^{-1} . Calc. for $\text{C}_{10}\text{H}_{14}\text{O}$: C, 79.95; H, 9.39%. Found: C, 79.02; H, 8.99%. The 2:4-dinitrophenylhydrazone, crystallized from methanol, had m.p. 146-147°, λ_{\max} 380 $\text{m}\mu$ (ϵ , 23,000). Calc. for $\text{C}_{16}\text{H}_{18}\text{O}_4\text{N}_4$: C, 58.17; H, 5.49; N, 16.76%. Found: C, 57.90; H, 5.50; N, 16.57%.

Irradiation of 1-Octene and Acetylacetone

A mixture of oct-1-ene (135 g) and acetylacetone (15.0 g) was irradiated with a 350-w lamp for 57 hours. After removal of the excess octene the residue was distilled to give a low-boiling fraction (87-107° at 0.1 mm) (21 g) and a higher fraction (7 g). Redistillation of the main fraction through a spinning band column gave material, b.p. 90° at 0.1 mm, n_D^{25} 1.4455 (16.6 g), which consisted of two components in the ratio of approximately 3:2 as indicated by g.l.c. analysis on an SE 30 at 207°. Separation preparatively by this means was not possible because of the instability of the diketones at that temperature and decomposition rendered difficult the determination of the exact ratio of products even on the analytical column. The separated fractions were ozonized in chloroform solution cooled in CO_2 -acetone (to remove cyclized contaminants), the ozonide decomposed with water, the organic layer extracted with sodium hydrogen carbonate, and the residual oil distilled (ca. 140° at 0.3 mm).

The first peak gave 5-acetylundecan-2-one, n_D^{25} 1.4500, ν_{\max} 1719 cm^{-1} . Calc. for $\text{C}_{13}\text{H}_{24}\text{O}_2$: C, 73.53; H, 11.39%. Found: C, 73.54; H, 11.36%.

The second peak gave 4-acetyldecane-2-one, n_D^{25} 1.4466, ν_{\max} 1718 cm^{-1} . Calc. for $\text{C}_{13}\text{H}_{24}\text{O}_2$: C, 73.53; H, 11.39%. Found: C, 73.50; H, 11.25%.

Irradiation of Isopropenyl Acetate and Acetylacetone

A mixture of isopropenyl acetate (35 g), acetylacetone (15 g), and cyclohexane (160 ml) was irradiated with an 80-w lamp for 186 hours. After removal of the cyclohexane the residual oil was taken up in chloroform and the chloroform washed with sodium hydrogen carbonate. Evaporation of the chloroform gave the crude adduct (6.7 g).

The adduct (4 g) in methanol (150 ml) containing sodium hydroxide (2 N; 5 ml) was refluxed for 1 hour. The mixture was neutralized with carbon dioxide, evaporated, water added, and the mixture extracted with methylene dichloride. The organic phase was then extracted with sodium hydroxide (2 N; 4 × 20 ml), the aqueous extract acidified with sulphuric acid, and the phenolic material (1.04 g) extracted with carbon tetrachloride and distilled *in vacuo*.

The phenol (XXI) had an infrared spectrum (CCl_4) identical with that reported in the literature (25) and on bromination (26) in acetic acid gave tribromo-*m*-xylenol, m.p. (from cyclohexane) 162-163° (Anselmino gives 166-167°). Evaporation of the methylene dichloride layer gave 1.57 g of neutral material, probably unsaturated ketones, which was not further investigated.

Attempted separation of the uncyclized ketones by g.l.c. on DEGS (prep.) led to condensation reactions and decomposition.

Irradiation of 1-Methylcyclohexene and Acetylacetone

(a) Acetylacetone (20 g) in 1-methylcyclohexene (180 ml) was irradiated with a 350-w lamp for 56 hours. After removal of the excess hydrocarbon the residual oil was distilled (80-88° at 0.1 mm) to give the crude adduct (25 g).

(b) A mixture of acetylacetone (20 g), methylcyclohexene (130 ml), and cyclohexane (40 ml) was irradiated for 90 hours. Isolation of the product and distillation (78-90° at 0.15 mm) gave the crude mixture of ketones (28.5 g). This contained three main components but separation by g.l.c. preparatively was not possible because of condensation reaction induced by the high temperature required. Fractional distillation through a spinning band column gave the main product, (XV), in about 50% yield, b.p. 77° at 0.4 mm, n_D^{25} 1.4739. Calc. for $\text{C}_{12}\text{H}_{20}\text{O}_2$: C, 73.43; H, 10.27%. Found: C, 72.85; H, 9.86%.

The dioxime (hydroxylamine hydrochloride - pyridine at room temperature), crystallized from methanol, had m.p. 175-175.5°. Calc. for $C_{12}H_{22}O_2N_2$: C, 63.68; H, 9.80; N, 12.38%. Found: C, 63.78; H, 9.76; N, 12.09%.

Base-catalyzed Cyclization of Diketone (XV)

A solution of the diketone (XV) (7.0 g) in methanol (150 ml) containing sodium hydroxide (50 mg) was refluxed for 1 hour. The mixture was then neutralized with carbon dioxide, evaporated, diluted with water, and extracted with carbon tetrachloride. The crude material obtained on evaporation (5.8 g) consisted of two products in the ratio of 4:1 separable by g.l.c. on a preparative 10-ft DEGS column at 175°.

The main product, (XVI), had n_D^{25} 1.5154, λ_{max} 237 $m\mu$ (ϵ , 16,400), ν_{max} 1668, 1637, 1421 cm^{-1} . Calc. for $C_{12}H_{18}O$: C, 80.55; H, 10.18%. Found: C, 80.43; H, 10.14%. The 2:4-dinitrophenylhydrazone, crystallized from methanol, had m.p. 189-190°, λ_{max} 372 $m\mu$ (ϵ , 24,500). Calc. for $C_{18}H_{22}O_4N_4$: C, 60.32; H, 6.19; N, 15.63. Found: C, 60.78; H, 6.21; N, 15.52%.

The minor product (XVII) had n_D^{25} 1.5121, λ_{max} 240 $m\mu$ (ϵ , 17,000), ν_{max} 1670, 1637, 1415 cm^{-1} . Calc. for $C_{12}H_{18}O$: C, 80.85; H, 10.18%. Found: C, 80.14; H, 9.92%.

The 2:4-dinitrophenylhydrazone, crystallized from methanol, had m.p. 146-147°, λ_{max} 386 $m\mu$ (ϵ , 25,700). Calc. for $C_{18}H_{22}O_4N_4$: C, 60.32; H, 6.19; N, 15.63%. Found: C, 60.54; H, 6.19; N, 15.37%.

Ozonolysis of the Ketone (XVI)

The unsaturated ketone (XVI) (800 mg) was dissolved in methylene chloride (20 ml), immersed in an acetone-CO₂ bath, and a stream of ozone was passed for 1 hour. Hydrogen peroxide (30%; 2 ml) and aqueous sodium hydroxide (2 *N*; 5 ml) were added and the mixture stirred at room temperature for 5 hours. The mixture was extracted with methylene chloride, the aqueous phase acidified with sulphuric acid (3 *N*), and the acidic material isolated with carbon tetrachloride. Treatment of the crude acid with ethereal diazomethane gave the keto ester mixture (710 mg), which was separated by g.l.c. on a DEGS preparative column at 180° into two isomers in approximately equal amounts.

The keto-ester-I (XVIII) had n_D^{25} 1.4713. Calc. for $C_{12}H_{20}O_3$: C, 67.89; H, 9.50%. Found: C, 68.11; H, 9.33%. The 2:4-dinitrophenylhydrazone, crystallized from methanol, had m.p. 118-119°, λ_{max} 363 $m\mu$ (ϵ , 22,500). Calc. for $C_{18}H_{24}O_6N_4$: C, 55.09; H, 6.17; N, 14.28%. Found: C, 55.34; H, 6.22; N, 14.21%.

The keto-ester-II (XVIII) had n_D^{25} 1.4697. Calc. for $C_{12}H_{20}O_3$: C, 67.89; H, 9.50%. Found: C, 67.62; H, 9.18%. The 2:4-dinitrophenylhydrazone, crystallized from methanol, had m.p. 123-124°, λ_{max} 361 $m\mu$ (ϵ , 20,500). Calc. for $C_{18}H_{24}O_6N_4$: C, 55.09; H, 6.17; N, 14.28%. Found: C, 55.51; H, 6.34; N, 14.14%. The 2:4-dinitrophenylhydrazone did not show a mixed melting point depression on admixture with that from (XVIII), but showed different infrared and n.m.r. spectra.

Ozonolysis of the Ketone (XVII)

The unsaturated ketone (100 mg) was dissolved in methylene dichloride (30 ml), cooled in an acetone-CO₂ bath, and ozone was passed for 40 minutes. Hydrogen peroxide (30%; 2 ml) and aqueous sodium hydroxide (5 *N*; 5 ml) were added and the mixture stirred at room temperature for 5 hours. After removal of the neutral material by extraction the mixture was acidified with sulphuric acid (3 *N*), the acid extracted with carbon tetrachloride and esterified with diazomethane. The oil (80 mg) appeared homogeneous to g.l.c. on a DEGS column. Distillation (bath temp. -180° at ca. 0.6 mm) gave an oil, n_D^{25} 1.4689. Calc. for $C_{12}H_{18}O_3$: C, 67.89; H, 9.50%. Found: C, 67.59; H, 9.94%. The 2:4-dinitrophenylhydrazone, crystallized from methanol, had m.p. 153-154°, λ_{max} 361 $m\mu$ (ϵ , 21,600). Calc. for $C_{18}H_{24}O_6N_4$: C, 55.09; H, 6.17; N, 14.28%. Found: C, 55.29; H, 6.13; N, 14.22%.

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