Organic and Biological Chemistry

Evidence for Cyclohexyne and Cyclopentyne as Intermediates in the Coupling Reactions of Phenyllithium with 1-Chlorocyclohexene and 1-Chlorocyclopentene[1,2]

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Phenyllithium and 1-chlorocyclohexene and 1-chlorocyclopentene react at 150° in ether to form 1-phenylcyclohexene and 1-phenylcyclopentene, respectively. A 1:1 mixture of 1-chlorocyclohexene-2-^{14}C and 1-chlorocyclohexene-6-^{14}C with phenyllithium yielded 1-phenylcyclohexene-x-^{14}C which contained 23% of the ^{14}C label in the 1-position. When 1-chlorocyclopentene-1-^{14}C was heated with phenyllithium, extensive rearrangement of the ^{14}C label occurred with 48.9, 36.2, and 14.9% of the ^{14}C distributed in the 1-, 2-, and 5-positions of 1-phenylcyclopentene, respectively. The observed ^{14}C rearrangements which accompanied these nucleophilic substitution reactions are best rationalized in terms of an elimination–addition mechanism involving cycloalkyne intermediates.

Introduction

In recent years it has been shown that a variety of nucleophilic substitution reactions of nonactivated aromatic halides proceed *via* the elimination–addition mechanism involving benzyne-type intermediates. For example, this mechanistic course has been established for the amination of aryl halides by alkali amides in liquid ammonia,[4] the coupling of aryl halides with phenyllithium,[5] and the high-temperature alkaline hydrolysis of aryl halides.[6] The successful application of the elimination–addition mechanism to the substitution reactions of nonactivated aryl halides prompted a study of the substitution reactions of nonactivated cyclic vinyl halides of the common ring sizes.[1]

The elimination–addition mechanism has been adequately demonstrated for a number of substitution reactions of nonactivated, acyclic vinyl halides. Some of the first systems to be investigated were the reaction of vinyl chloride and sodium ethoxide to form ethyl vinyl ether,[7] base-catalyzed substitution of *cis*-dichloroethylene,[8] *trans*-1-chloro-2-(*p*-tolylmercapto)ethene,[9] and trichloroethylene[10] with thiols, and the reaction of vinyl bromide with potassium sulfite.[11] Strong bases and elevated temperatures appear to facilitate the elimination–addition mechanism.

In considering elimination–addition mechanisms for cyclic vinyl halides, special interest is attached to the possible formation of highly strained cyclic acetylenic intermediates which, like benzyne, might not be isolable under ordinary conditions. The limited information that is available concerning the chemistry of cycloalkynes strongly suggests that cyclohexyne and cyclopentyne would be unstable, highly reactive compounds. In 1933, Ruzicka[12] synthesized the first cycloalkynes, cyclopentadecyne and cycloheptadecyne, by heating the appropriate 1-bromocycloalkenes with alcoholic potassium hydroxide. Blomquist[13] has prepared pure cyclodecyne, cyclononyne, and cyclooctyne, the smallest cycloalkyne which has been isolated. In 1912, Favorskii[14] suggested that cyclohexyne is a reaction intermediate in the formation of tristetramethylenebenzene by the action of sodium on 1,2-dibromocyclohexene. 1,2-Dibromocyclopentene and sodium yield tristrimethylenebenzene in a similar manner.[15] Wittig[16] has reported the trapping of cycloheptyne, cyclohexyne, and cyclopentyne as their Diels–Alder adducts with diphenylisobenzofuran. The

(1) For preliminary reports of this work see F. Scardiglia and J. D. Roberts, *Tetrahedron*, 1, 343 (1957), and L. K. Montgomery and J. D. Roberts, *J. Am. Chem. Soc.*, 82, 4750 (1960).

(2) Supported in part by the National Science Foundation and the Petroleum Research Fund administered by the American Chemical Society. Grateful acknowledgment is hereby made to the Donors of the Petroleum Research Fund.

(3) (a) General Electric Company Fellow, 1959–1960; (b) National Science Foundation Predoctoral Fellow, 1954–1955.

(4) (a) J. D. Roberts, H. E. Simmons, Jr., L. A. Carlsmith, and C. W. Vaughan, *J. Am. Chem. Soc.*, 75, 3290 (1953); (b) J. D. Roberts, D. A. Semenow, H. E. Simmons, Jr., and L. A. Carlsmith, *ibid.*, 78, 601 (1956).

(5) (a) G. Wittig, G. Pieper, and G. Fuhrmann, *Ber.*, 73, 1193 (1940); (b) G. Wittig, *Angew. Chem.*, 69, 245 (1957); (c) R. Huisgen and H. Rist, *Naturwiss.*, 41, 358 (1954); (d) R. Huisgen and H. Rist, *Ann.*, 594, 137 (1955); (e) E. Jenny and J. D. Roberts, *Helv. Chim. Acta*, 38, 1248 (1955).

(6) (a) J. D. Roberts, A. T. Bottini, and D. A. Semenow, *Science*, 122, 881 (1955); (b) A. T. Bottini and J. D. Roberts, *J. Am. Chem. Soc.*, 79, 1458 (1957); (c) A. Luttringhaus and D. Ambros, *Ber.*, 89, 463 (1956).

(7) W. Reppe, German Patents, 550, 403 (1928) and 584, 840 (1933); *Chem. Abstr.*, 26, P4825 (1932); 28, P1058 (1934).

(8) W. E. Truce, M. M. Boudakian, R. F. Heine, and R. J. McManimie, *J. Am. Chem. Soc.*, 78, 2743 (1956).

(9) W. E. Truce and M. M. Boudakian, *ibid.*, 78, 2748 (1956).

(10) (a) A. F. Montanari and A. Negrini, *Boll. sci. fac. chim. ind. Bologna*, 15, 27 (1957); *Chem. Abstr.*, 51, 12849 (1957); (b) W. E. Truce and R. Kassinger, *J. Am. Chem. Soc.*, 80, 1916 (1958).

(11) W. E. Truce and M. M. Boudakian, *ibid.*, 78, 2752 (1956).

(12) L. Ruzicka, M. Hürbin, and H. A. Boekenoogen, *Helv. Chim. Acta*, 16, 498 (1933).

(13) (a) A. T. Blomquist, R. E. Burge, Jr., and A. C. Sucsy, *J. Am. Chem. Soc.*, 74, 3636 (1952); (b) A. T. Blomquist, L. H. Liu, and J. C. Bohrer, *ibid.*, 74, 3643 (1952); (c) A. T. Blomquist and L. H. Liu, *ibid.*, 75, 2153 (1953).

(14) A. E. Favorskii and V. Boshowskii, *Ann.*, 390, 122 (1912).

(15) A. E. Favorskii, *J. Gen. Chem. USSR*, 6, 720 (1936).

(16) G. Wittig, A. Krebs, and R. Pohlke, *Angew. Chem.*, 73, 324 (1960).

Table I. Radioactivity Analyses of 1-Phenylcyclohexene-x-^{14}C and Related Compounds

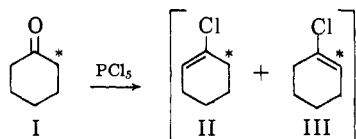| Compd.	Measured activity[a,b]	Relative activity, %
1-Phenyl-2-(2,4-dinitrobenzenemercapto)cyclohexene-x-^{14}C	0.1217 ± 0.0006	(100)
Benzoic acid-α-^{14}C (X)	0.02797 ± 0.00016	23.0 ± 0.3
1-Phenyl-2-(2,4-dinitrobenzenemercapto)cyclohexene-2-^{14}C and -6-^{14}C (equimolar mixture)	0.1968 ± 0.0026	(100)
Benzoic acid (XI)	0.0002 ± 0.0002	0.1 ± 0.1

[a] Activities in microcuries per millimole (μc./mmole). [b] Uncertainties quoted are probable errors.

cycloalkynes were generated by two independent methods, the action of magnesium in tetrahydrofuran on 1,2-dihalocycloalkenes and the oxidation of 1,2-cycloalkanedione dihydrazones.

Little is known concerning the reactions of strongly basic nucleophiles with nonactivated, cyclic vinyl halides. Wittig and Harborth[17] have reported 5% yields of 1-phenylcyclohexene from 1-chlorocyclohexene and phenyllithium in ether at 100°. The possibility that this (and similar) reactions proceed by way of a cycloalkyne intermediate was the subject of the present investigation.

Results and Discussion

The mechanism of the nucleophilic substitution reaction of phenyllithium with 1-chlorocyclohexene has been investigated using ^{14}C-labeled 1-chlorocyclohexene. Cyclohexanone-2-^{14}C (I) was treated with phosphorus pentachloride. Distillation of the crude products, 1,1-dichlorocyclohexane and 1-chlorocyclohexene, promoted extensive dehydrohalogenation of the dichloride. Equimolar quantities of 1-chlorocyclohexene-6-^{14}C (II) and 1-chlorocyclohexene-2-^{14}C (III) should be formed, since hydrogen chloride should be eliminated in the two possible ways with equal probability, provided, of course, that kinetic isotope effects can be neglected.[18] The ^{14}C-labeled 1-chloro-


hexene was heated with phenyllithium in ether in a steel bomb at 150°. A 28% yield of 1-phenylcyclohexene-x-^{14}C was obtained. The substitution product was converted to the solid derivative, 1-phenyl-2-(2,4-dinitrobenzenemercapto)cyclohexene-x-^{14}C, with 2,4-dinitrosulfenyl chloride. Oxidation of the derivative with sodium permanganate afforded benzoic-α-^{14}C acid (X). The ^{14}C activities of the 2,4-dinitrobenzenemercapto derivative and the benzoic acid are reported in Table I. About 23% of the total radioactivity in the substitution product was present as 1-phenylcyclohexene-1-^{14}C (IX). In order to show that the observed isotope rearrangement which accompanied substitution did not occur during the degradation sequence, the following control experiment was performed. Cyclohexanone-2-^{14}C (I) was converted to a 1:1 mixture of 1-phenylcyclohexene-2-^{14}C and 1-phenylcyclohexene-6-^{14}C by treatment with phenyllithium and dehydration of the resulting alcohol

(17) G. Wittig and G. Harborth, *Ber.*, **77**, 306 (1944).
(18) In the discussions that follow, kinetic isotope effects are assumed to be negligible unless explicitly considered.

with sulfuric acid. The 1-phenylcyclohexene which was so labeled was degraded following the scheme used previously. The benzoic acid XI obtained in this manner contained 0.1 ± 0.1% of the radioactivity of the 2,4-dinitrobenzenemercapto derivative (Table I).

If the coupling reaction of 1-chlorocyclohexene and phenyllithium had occurred by way of direct nucleophilic substitution, no 1-phenylcyclohexene-1-^{14}C (IX) would have been produced. On the other hand, if the substitution reaction followed the elimination–addition route, cyclohexyne-3-^{14}C (IV) and cyclohexyne-1-^{14}C (V) would have been the intermediates. Since each isotopically labeled cyclohexyne can add phenyllithium in two equally probable ways, the ^{14}C label should have been distributed equally among the 1- (IX), 2- (VIII), 3- (VI), and 6-(VII) positions of the substitution product. The observed 23% yield of 1-phenylcyclohexene-1-^{14}C (IX) is in substantial accord
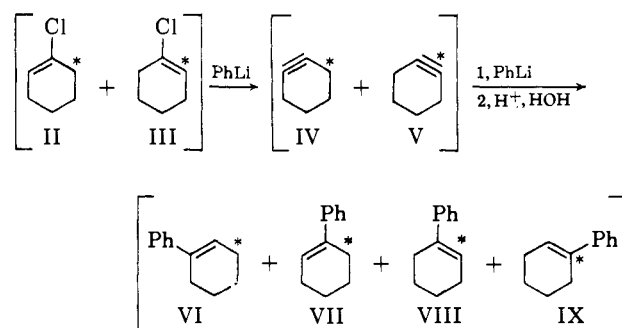
with this mechanistic model. The small difference between the experimentally observed and theoretically predicted values may be due to competition with some nonrearranging substitution process or to inter- and intramolecular isotope effects in the preparation of the starting vinyl chloride, the substitution process, or the degradation sequence.

In an attempt to extend the study of nucleophilic substitution processes of nonactivated cyclic vinyl halides to smaller ring systems, 1-chlorocyclopentene was heated with phenyllithium in ether at 150° for 1.3 hr. A 30% yield of 1-phenylcyclopentene was formed. The mechanism of this coupling reaction was investigated by carrying out the reaction of 1-chlorocyclopentene-1-^{14}C (XIV) and phenyllithium.

The radioactive chloride was synthesized from adipic-1,6-^{14}C$_2$ (XII) by way of cyclopentanone-1-^{14}C (XIII). In order to demonstrate that the ^{14}C label was in the 1-position, 1-chlorocyclopentene-1-^{14}C (XIV) was hydrolyzed to cyclopentanone-1-^{14}C (XIII) which was in turn converted to 1-phenylcyclopentene-1-^{14}C. Degradation of the 1-phenylcyclopentene-1-^{14}C following the scheme outlined in Figure 1 gave benzoic-α-^{14}C acid (XXIX) which contained 97.3 ± 0.7% (Table II) of the ^{14}C label. This reaction sequence not

Table II. Radioactivity Analyses of the Degradation Products of 1-Phenylcyclopentene-x-^{14}C and 1-Chlorocyclopentene-1-[14]C

Compd.	Measured activity[a,b]	Relative activity, %[c]
1-Phenylcyclopentene-1-[14]C (XV)		48.9
5-Phenyl-5-oxopentanoic-x-^{14}C acid semicarbazone (XVI)	2.331 ± 0.002	(100)
Benzoic-α-^{14}C acid (XVII)	1.339 ± 0.007	48.9 ± 0.8 (XVI)
Benzoic-α-^{14}C acid (XXI)	1.091 ± 0.007	46.8 ± 0.8 (XVI)
Succinic-x-^{14}C acid (XVIII)	1.172 ± 0.005	50.3 ± 0.7 (XVI)
1-Phenylcyclopentene-2-[14]C (XXVI)		36.2
CO$_2$[d] (XXIII)	0.844 ± 0.003	36.2 ± 0.5 (XVI)
4-Phenyl-1-aminobutane-x-[14]C[e] (XXII)	1.461 ± 0.009	62.7 ± 0.8 (XVI)
1-Phenylcyclopentene-5-[14]C (XXVII)		14.9
Succinic-x-^{14}C acid[f] (XVIII)	0.470 ± 0.002	(100)
2CO$_2$[d] (XX)	0.466 ± 0.003	99.2 ± 1.1 (XVIII)
1,2-Diaminoethane-x-[14]C[g] (XIX)	0.000 ± 0.001	0.0 ± 0.3 (XVIII)
1-Chlorocyclopentene-1-[14]C[h]		
5-Phenyl-5-oxopentanoic-x-^{14}C acid semicarbazone (XXVIII)	1.150 ± 0.004	(100)
Benzoic-α-^{14}C acid (XXIX)	1.119 ± 0.004	97.3 ± 0.7 (XXVIII)

[a] Activities in microcuries per millimole (μc./mmole). [b] Uncertainties quoted are probable errors. [c] Relative to the compound indicated in parentheses. [d] CO$_2$ as barium carbonate. [e] 4-Phenyl-1-aminobutane-x-^{14}C as benzamide. [f] Succinic-x-^{14}C acid (XVIII), diluted. [g] 1,2-Diaminoethane-x-[14]C (XIX) as dibenzamide. [h] 1-Chlorocyclopentene-1-^{14}C, diluted.

only confirms the presence of the ^{14}C label in the 1-position of the 1-chlorocyclopentene, but it also offers a check on the degradation procedure.
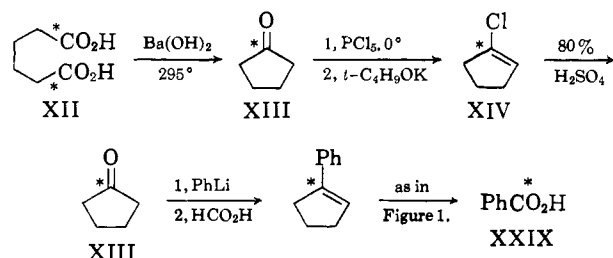
The reaction of 1-chlorocyclopentene-1-[14]C (XIV) and phenyllithium was carried out under conditions similar to those employed for the coupling reaction with nonlabeled chloride. The 1-phenylcyclopentene-x-[14]C (XV) which was obtained was degraded using the series of reactions shown in Figure 1. The ^{14}C analyses

46.8 ± 0.8%) obtained directly from the oxidation of 1-phenylcyclopentene-x-[14]C (XV) and the benzoic-α-^{14}C acid (XVII, 48.9 ± 0.8%) from the oxidation of 5-phenyl-5-oxopentanoic-x-^{14}C acid semicarbazone (XVI). This difference is not much greater than the combined probable errors of the two values. Moreover, the 1-phenylcyclopentene-x-[14]C (XV) oxidation was conducted in the presence of 1–2 mole % of ethylbenzene[19] and an even larger amount of biphenyl.[19] Oxidation of either of these hydrocarbons to benzoic acid would lower the activity of the benzoic-α-^{14}C acid (XXI).

Clearly, the coupling reaction proceeds with rearrangement, for 48.9, 36.2, and 14.9% of the ^{14}C-label was distributed in the 1- (XXV), 2- (XXVI), and 5- (XXVII) positions, respectively, of the 1-phenylcyclopentene-x-[14]C (XV). A direct nucleophilic displacement would yield only 1-phenylcyclopentene-1-[14]C (XXV). In contrast, coupling *via* the elimination–
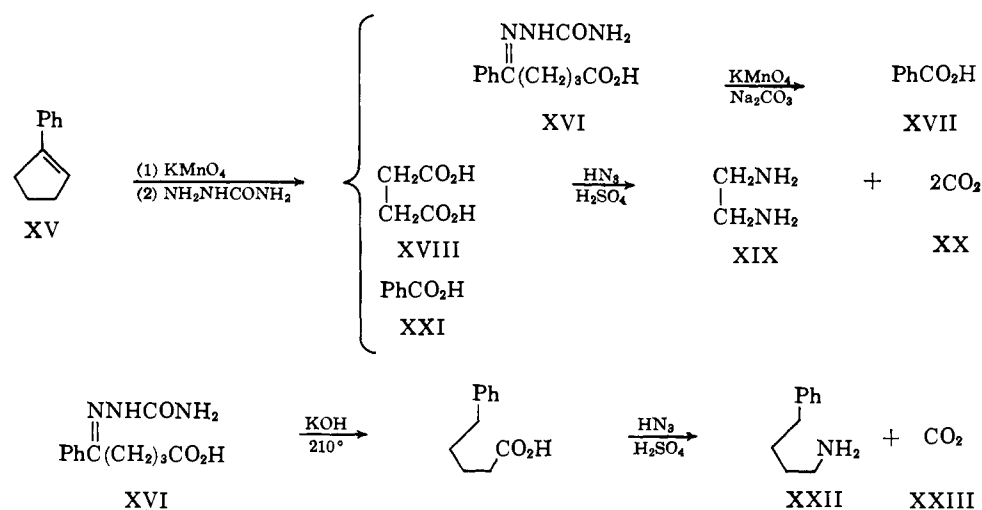

Figure 1.—Degradation scheme for 1-phenylcyclopentene-x-[14]C.

of the degradation products are summarized in Table II. In general, there was good experimental agreement among the activities of the various degradation products. The single exception was the lack of agreement between the activities of the benzoic-α-^{14}C acid (XXI,

addition mechanism with the intervention of a cyclopentyne (XXIV) intermediate would afford a

(19) Phenyllithium reacts with ether at elevated temperatures to form ethylbenzene as well as a number of other products. Biphenyl is a by-product in the preparation of phenyllithium.

XIV → XXIV →

$$\left[\begin{array}{ccc} \text{XXV} & \text{XXVI} & \text{XXVII} \\ 48.9\% & 36.2\% & 14.9\% \end{array} \right]$$
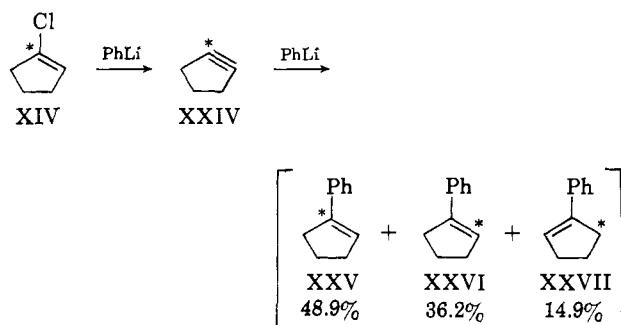
1:1 mixture of 1-phenylcyclopentene-1-^{14}C (XXV) and 1-phenylcyclopentene-2-^{14}C (XXVI). The amount of 1-phenylcyclopentene-1-^{14}C (XXV) observed experimentally (48.9%) is in good agreement with the predicted value for elimination–addition. The 14.9% of 1-phenylcyclopentene-5-^{14}C (XXVII) formed very likely arises from a base-induced (phenyllithium or lithium ethoxide) allylic rearrangement. This sequence of steps does not seem unreasonable considering
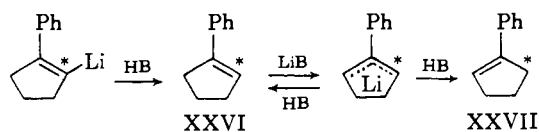
that the reaction is conducted in a stainless steel bomb at 150°. Phenyllithium attacks ether rapidly at this temperature. Although vinyllithium is somewhat more stable than phenyllithium toward ether at room temperature,[20] it is doubtful that a marked difference in stability between these two compounds would be observed at 150°.

It is possible to rationalize the observed isotope rearrangements which accompany the coupling reactions of ^{14}C-labeled 1-chlorocyclohexene and 1-chlorocyclopentene with phenyllithium without invoking cycloalkyne intermediates. For example, the rearrangements can be formulated in terms of competing direct nucleophilic displacement and a displacement mechanism that proceeds with rearrangement. The elimination–addition mechanism offers several advantages over such a scheme. First, the intervention of cycloalkyne intermediates readily accounts for the fact that rearrangement occurs; and, in addition, it explains why the extent of rearrangement is about 50% in both five- and six-membered ring systems. In marked contrast, few reasonable, alternative rearrangement mechanisms can be written. Secondly, it has been noted[21] that the reaction of 1-chlorocyclohexene with nucleophiles is favored as the basicity of the nucleophile increases and as the reaction temperature is increased. Typical observations[21] are as follows. 1-Chlorocyclohexene does not react with sodium ethoxide in refluxing ethanol. About 61% of the starting chloride was recovered unreacted when the same reactants were heated at 220° for 15 hr. Alkali amides in liquid ammonia react rapidly with 1-chlorocyclohexene affording only polymeric products. While these observations are at best suggestive with regard to the mechanism of the phenyllithium substitution

(20) D. Seyferth and M. A. Weiner, J. Am. Chem. Soc., 83, 3583 (1961).
(21) F. Scardiglia, Ph.D. Thesis, California Institute of Technology, 1958, pp. 53, 54.

reactions, they are most certainly compatible with elimination being the first and rate-determining step in the coupling process.

One alternative mechanism which merits discussion is an elimination–addition pathway involving cycloallenic intermediates. Whereas nonactivated aryl halides can yield only one 1,2-elimination product, benzyne, cyclic vinyl halides can give either a cycloalkyne or a cycloallene. Moore and Ward[22] have carried out the equilibration of cycloallenes and cycloalkynes in nine-, ten-, and eleven-membered rings. As the ring size was decreased, the ratio of cycloallene to cycloalkyne increased. The 1,2-cyclononadiene to cyclononyne ratio was about 11:1 (120°, potassium *t*-butoxide in *t*-butyl alcohol). Moore and Ward suggested that bond-angle distortion was the major effect in determining the allene to alkyne ratio, although they acknowledged that other factors might well be important. Should their observed trend continue to smaller ring systems, the five- and six-membered cycloallenes might well be considerably more stable than their isomeric cycloalkynes. While the 1,2-elimination reactions of cyclic vinyl halides need not yield the most stable of possible elimination products, this study certainly suggests that cycloallenic intermediates should be carefully considered.

The patterns of isotope rearrangement which are observed in the coupling reactions of 1-chlorocyclohexene and 1-chlorocyclopentene with phenyllithium can be obtained by way of an elimination–addition sequence involving cycloallenic intermediates, provided that suitable assumptions are made. Considering the reaction of 1-chlorocyclopentene-1-^{14}C with phenyllithium, for example, the observed percentage of ^{14}C in the 1-, 2-, and 5-positions (48.9, 36.2, and 14.9%, respectively) of the substitution product can be obtained by assuming that one-half of the phenyllithium adds to the middle and one-half to the ends of the allenic system XXX and further that the 2-lithio-3-phenylcyclopentene-2-^{14}C (XXXII) formed rearranges to 1-phenylcyclopentene-2-^{14}C (XXVI). This mechanism cannot be criticized too severely for the necessity of having to rearrange the double bond of 2-lithio-3-phenylcyclopentene-2-^{14}C (XXXII) into conjugation with the phenyl ring, since both of the elimination–addition mechanisms require that 30% of the 1-phenylcyclopentene-2-^{14}C (XXVI) be isomerized to 1-phenylcyclopentene-5-^{14}C (XXVII). It is not obvious, however, why the 2-lithio-3-phenylcyclopentene-2-^{14}C
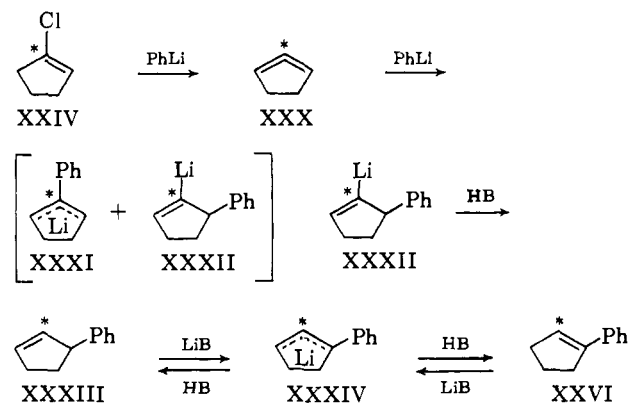
(22) W. R. Moore and H. R. Ward, J. Am. Chem. Soc., 85, 86 (1963).

(XXXII) should isomerize quantitatively to 1-phenyl-cyclopentene-2-[14]C (XXXVI) while only 30% (60% of the allylic intermediate must be formed) of the latter material continues on to 1-phenylcyclopentene-5-[14]C (XXVII).

A second objection to cycloallenic intermediates concerns the attack of phenyllithium on the allenic system. Even though aryne intermediates are highly reactive, they display a remarkable orientation selectivity toward attacking nucleophiles.[23] It would therefore not be surprising if a cycloallenic intermediate added phenyllithium selectively, perhaps to form the more stable[24] allylic anion (XXXI). For this mechanism to be compatible with the experimentally determined ^{14}C distribution, the allenic intermediate XXX must display some measure of selectivity since a statistical addition of phenyllithium was not observed. In view of this selectivity, it is hard to believe that phenyllithium should add to both five- and six-membered ring allenic intermediates to give essentially identical (within experimental error) portions of middle addition to end addition. For these reasons it appears that these coupling reactions are best formulated in terms of an elimination–addition mechanism proceeding via cycloalkyne intermediates.

Experimental

Melting points and boiling points are uncorrected. Analyses were performed by Dr. Adalbert Elek, Elek Microanalytical Laboratories, Los Angeles, Calif. Nuclear magnetic resonance (n.m.r.) spectra were taken at 60 Mc.p.s. on a Varian Associates Model V4300D spectrometer. Chemical shifts are quoted in parts per million (p.p.m.) relative to tetramethylsilane as an internal standard. Infrared spectra were determined using a Perkin-Elmer double-beam infrared spectrometer, Model 21. Vapor-phase chromatographs (v.p.c.) were obtained with either a Perkin-Elmer vapor fractometer, Model 154-B, or an F and M Model 202A gas chromatograph.

Radioactivity Analyses. Samples were converted to carbon dioxide following the oxidation procedure suggested by Van Slyke and Folch.[25] Specific activities were determined using an ionization chamber and a vibrating-reed electrometer from the Applied Physics Corporation, Model 30.

Cyclopentanone-1-[14]C (XIII). Adipic-1,6-[14]C$_2$ acid[26] (0.0471 g., total activity 1.0 mc.) was washed with reagent acetone into a 500-ml., round-bottomed flask containing 29.05 g. of adipic acid. A total of 100 ml. of acetone was added. All of the adipic acid did not go into solution, and the mixture was digested on a steam bath for 15 min. The solvent was removed affording 29.10 g. (0.2000 mole, specific activity 5.0 μc./mmole) of adipic-1,6-[14]C$_2$ acid (XII).

Barium hydroxide pentahydrate (2.00 g., 0.00635 mole) was ground to a fine powder. Portions of adipic-1,6-[14]C$_2$ acid (XII) were blended into the powder

(23) J. D. Roberts, C. W. Vaughan, L. A. Carlsmith, and D. A. Semenow, *J. Am. Chem. Soc.*, **78**, 611 (1956).

(24) (a) A. I. Shatenshtein in "Advances in Physical Organic Chemistry," Vol. I, V. Gold, Ed., Academic Press Inc., New York, N. Y., 1963, pp. 177–179; (b) S. I. Miller and W. G. Lee, *J. Am. Chem. Soc.*, **81**, 6313 (1959).

(25) D. D. Van Slyke and J. Folch, *J. Biol. Chem.*, **136**, 509 (1940).

(26) Supplied by Merck and Co., Ltd.

until a total of 29.10 g. (0.2000 mole) had been added. This mixture was transferred to a 50-ml. modified Claisen flask with a 10-cm. Vigreux column and condenser. The flask was sealed off with a hand torch so that the condenser outlet was the only opening in the system. The Claisen flask was connected to a 50-ml., two-necked flask which was in turn connected to a 2-l., three-necked, round-bottomed flask. The large three-necked flask was fitted with a mechanical stirrer, filled with 1 l. of saturated barium hydroxide solution, and connected to a wash bottle with a fritted-glass bubbler which was filled with saturated barium hydroxide solution.

The reaction flask was immersed in a Woods metal bath which was heated by a heating mantle. Power input to the heating mantle was controlled by a relay actuated by a thermocouple in the bath. The temperature of the bath was raised from 100 to 290° over a 1.0-hr. period and then maintained at 288 ± 2° for 1.5 hr. Six additional hours of heating at 293 ± 2° were required for completion of the reaction.

Anhydrous potassium carbonate was added to the cyclopentanone–water mixture obtained as distilled reaction products. The upper, cyclopentanone, phase was removed with a dropper; the aqueous phase was washed six times with 3-ml. portions of methylene chloride. The methylene chloride extracts were combined with the separated cyclopentanone phase and dried over 0.5 g. of anhydrous potassium carbonate. Distillation was accomplished through a semimicro column.[27] Cyclopentanone-1-[14]C (XIII, 15.948 g., 95%), b.p. 127–128°, n^{20}D 1.4368 (lit.[28] b.p. 130°, n^{20}D 1.4366), which gave a single peak in the v.p.c. (Perkin-Elmer, silicone rubber, 100°), was obtained.

The barium carbonate precipitated in the large three-necked flask, was collected by suction filtration, washed with filtered, distilled water, washed with filtered acetone, and dried for 3 days at 25° (0.1 mm.), yield 35.9 g. (91%).

1-Chlorocyclopentene-1-[14]C (XIV). Phosphorus pentachloride (49.5 g., 0.238 mole) and 200 ml. of methylene chloride were placed in a 300-ml., three-necked, round-bottomed flask fitted with mechanical stirrer, thermometer, and pressure-equalizing Hershberg dropping funnel. Cyclopentanone-1-[14]C (XIII, 15.95 g., 0.190 mole) and 15 ml. of methylene chloride were added over a 2.0-hr. period to the reaction mixture which was maintained at 0 ± 5°. The solution was stirred at about 5° for 1.0 hr.; finally, the reactants were allowed to warm to 20° during 1.0 hr.

The reaction mixture was added with mechanical stirring to 150 g. of crushed ice. The organic layer was separated, washed once with water, and washed twice by stirring with 200 g. of crushed ice and 50 ml. of 40% sodium hydroxide. After a final water wash, the methylene chloride solution was dried over 4 g. of anhydrous calcium chloride. The solvent was removed through a 20-cm. (13-mm. i.d.) column filled with 1.3 × 2.5 × 2.3 mm. Heli-Pak packing.

The crude halide mixture was refluxed for 2.0 hr. with 200 ml. of 0.8 M potassium *t*-butoxide in *t*-butyl

(27) C. W. Gould, Jr., G. Holzman, and C. Niemann, *Anal. Chem.* **20**, 361 (1948).

(28) I. Heilbron, "Dictionary of Organic Compounds," Vol. I, Oxford University Press, New York, N. Y., 1953, p. 646.

alcohol. The dehydrohalogenation products were poured into 500 ml. of water, and the halide was taken up in the methylene chloride. The aqueous layer was washed twice with solvent and the combined extracts were washed six times with water and dried over 10 g. of anhydrous calcium chloride. The solvent was removed using the Heli-Pak column and the residue was distilled through a semimicro column.[27] 1-Chloro-cyclopentene-1-^{14}C (XIV, 10.01 g., 52%), b.p. 102–103°, of about 98% purity (v.p.c., 2-m. (6.3-mm. o.d.) Perkin-Elmer column A, DC-200 silicone oil, 96°) was obtained.

Since the reported physical properties for 1-chlorocyclopentene are widely different,[29,30] they were carefully established using unlabeled 1-chlorocyclopentene. Contrary to the literature,[30] 1-chlorocyclopentene is reasonably stable if stored in a sealed tube in the absence of moisture or hydrochloric acid. A typical sample of 1-chlorocyclopentene which was homogeneous to v.p.c., b.p. 102–103°, n^{25}D 1.4638, did not react with alcoholic silver nitrate solution and had the correct elemental analysis.

Anal. Calcd. for C_5H_7Cl: C, 58.54; H, 6.88; Cl, 34.57. Found: C, 58.49; H, 7.00; Cl, 34.44.

The infrared spectrum of 1-chlorocyclopentene revealed only a single absorption in the carbon–carbon double-bond stretching region at 1628 cm.$^{-1}$. A strong band at 810 cm.$^{-1}$ is characteristic of the carbon–hydrogen out-of-plane deformation of a triply substituted double bond.[31] The n.m.r. spectrum of this halide consisted of a multiplet at 5.55 p.p.m. and a very complex absorption extending from 1.66 to 2.75 p.p.m.

Phenyllithium and 1-Chlorocyclopentene-1-^{14}C (XIV). 1-Chlorocyclopentene-1-^{14}C (XIV, 3.92 g., 0.00382 mole) was washed into a dry, 500-ml., stainless steel bomb with anhydrous ether. To the bomb was added 200 ml. (0.250 mole) of 1.25 M phenyllithium solution.[32] The bomb was sealed and heated in a thermostated oil bath at 150° for 1.25 hr. Finally, the bomb was cooled successively in air (5 min.), cold water (20 min.), and a Dry Ice–acetone mixture (5 min.). Cooling to Dry Ice temperature was necessary to prevent loss of other reaction products as the ethylene (formed by cleavage of the ether) escaped when the bomb was opened. The bomb was allowed to warm to room temperature, and the contents were washed out with ether and water.

A second run was made on an identical scale. The products were combined, washed four times with water, and dried over 15 g. of anhydrous calcium chloride. The ether was removed by distillation through the Heli-Pak column and the residue was distilled through a semimicro column.[27] The fractions were analyzed using v.p.c. (F and M column, 1.3-m. (4.8-mm. i.d.), silicone rubber, 175°). The yield of 1-phenylcyclo-pentene-x-^{14}C XV calculated from the v.p.c. analysis was 2.32 g. (21%), b.p. mainly 114° (14 mm.).

Oxidation of 1-Phenylcyclopentene-x-^{14}C (XV) with Neutral Potassium Permanganate. Only fractions which

contained no greater than 2% of ethylbenzene were oxidized. In a 500-ml. Morton flask fitted with high-speed stirrer and thermometer were placed 200 ml. of phosphate buffer (pH 7, prepared from 105 ml. of 0.128 M carbonate-free sodium hydroxide solution and 6.80 g. of potassium dihydrogen phosphate diluted to 200 ml.) and 8.77 g. (0.0555 mole) of potassium permanganate. The oxidizing solution was thermostated at 30°. 1-Phenylcyclopentene-x-^{14}C (XV, 2.04 g., 0.0142 mole), and 50 ml. of Spectrograde isooctane were added to the reaction flask and the stirrer was started (5000 r.p.m.). The temperature of the reaction rose to a maximum 43° in about 20 min.; the stirring was continued for 1.0 hr.

The aqueous phase of the reaction mixture was made strongly alkaline with 10% sodium hydroxide solution and continuously extracted with ether for 3.0 hr. The aqueous phase was acidified with 6 N sulfuric acid and continuously extracted with ether for 48 hr. The crude mixture of acids (1.98 g.) obtained from the extract was chromatographed on a 20-mm. column containing 40 g. of 100-mesh silicic acid, 10 g. of Hyflo-Supercel, and 45 g. of water. Chloroform was used as the solvent. All but 0.25 g. of the crude acid mixture dissolved in 30 ml. of chloroform. The solution of acids was put on the column, and 1.645 g. of a mixture of benzoic-α-^{14}C (XXI) and 5-phenyl-5-oxopentanoic-x-^{14}C acids was obtained using chloroform (450 ml.) as an eluent. The 0.25 g. of acid, which did not dissolve in chloroform, dissolved in 90:10 chloroform-n-butyl alcohol and was placed on the column. With successive use of 90:10 (300 ml.), 80:20 (250 ml.), and 75:25 chloroform–n-butyl alcohol mixtures as eluents, 0.215 g. of acid, m.p. 178.0–184.5°, was obtained. Attempts to purify this acid by recrystallization from various solvents were unsuccessful. Further purification of material on a similar silicic acid–Hyflo Supercel column using 85:15 chloroform–n-butyl alcohol as eluent afforded 0.146 g. (8.7%) of succinic-x-^{14}C acid (XVIII), m.p. 186.0–186.8° (lit.[33] m.p. 184.5–185.0°).

The 1.645 g. of mixed benzoic-α-^{14}C acid (XXI) and 5-phenyl-5-oxopentanoic-x-^{14}C acid obtained above was dissolved in 20 ml. of 95% ethanol. To this solution was added 4.8 g. (0.058 mole) of sodium acetate and 20 ml. of water; the solution was heated to the boiling point. Semicarbazide hydrochloride (3.2 g., 0.029 mole) was added and dissolved. As the solution cooled to room temperature, fine white needles formed. A 49% (1.732 g.) yield of 5-phenyl-5-oxopentanoic-x-^{14}C acid semicarbazone (XVI), m.p. 211–214° dec. (lit.[34] m.p. 212–213°), was obtained by collecting the needles (washing first with 50:50 ethanol–water and then with water) and recrystallizing them once from ethanol–water (50:50).

The mother liquor from the semicarbazone formation was acidified with 6 N sulfuric acid, steam distilled to remove much of the acetic acid, and continuously extracted with ether. To the crude acid obtained from the ether extract were added 0.8 g. (0.0075 mole) of sodium carbonate, 3 g. (0.0190 mole) of finely powdered potassium permanganate, and 35 ml. of water. The solution was heated at the reflux tempera-

(29) M. Mousseron and R. Jacquier, *Bull. soc. chim. France*, 648 (1950).
(30) E. A. Braude and W. F. Forbes, *J. Chem. Soc.*, 1755 (1951).
(31) L. J. Bellamy, "The Infrared Spectra of Complex Molecules," 2nd Ed., John Wiley and Sons, Inc., New York, N. Y., 1958, pp. 34–56.
(32) R. G. Jones and H. Gilman, *Org. Reactions.*, 6, 339 (1951).

(33) M. T. Leffler and R. Adams, *J. Am. Chem. Soc.*, 58, 1551 (1936).
(34) L. F. Fieser and J. Szmuszkovicz, *ibid.*, 70, 3352 (1948).

ture for 4.0 hr. The products were cooled, acidified with 6 N sulfuric acid, and heated for 1.0 more hr. Enough sodium bisulfite was then added to remove excess manganese dioxide. Benzoic acid crystallized as the solution was cooled and was collected by continuous extraction with ether. A single recrystallization of the acid obtained from the ether extract gave 0.292 g. (17%) of benzoic-α-^{14}C acid (XXI), m.p. 122.2–122.8° (lit.[35] m.p. 122.4°).

5-Phenylpentanoic-x-^{14}C acid was prepared from 5-phenyl-5-oxopentanoic-x-^{14}C acid semicarbazone by the Wolff–Kishner reduction. 5-Phenyl-5-oxopentanoic-x-^{14}C acid semicarbazone (XVI, 1.143 g., 0.00459 mole), potassium hydroxide pellets which had been finely pulverized prior to use, and 25 ml. of diethylene glycol were placed in a 50-ml., round-bottomed flask fitted with a solvent-stripping reflux condenser and a magnetic stirring bar. The temperature of the bath was raised to 220° over a 15-min. period, and maintained there for 2.5 hr. The products were poured into 75 ml. of water and acidified with 6 N sulfuric acid. Crude 5-phenylpentanoic-x-^{14}C acid (0.673 g., 82%), m.p. 55–59°, was obtained. Recrystallization of this material twice from pentane (Norit) and twice from water–ethanol (60:40) afforded 0.557 g. (69%) of small white plates, m.p. 61.0–61.4° (lit.[36] m.p. 61°).

Schmidt Degradation of 5-Phenylpentanoic Acid. A reaction train was assembled similar to that described previously,[4b] consisting of a barium hydroxide (saturated solution, about 0.3 M) wash bottle, a soda-lime trap, reaction flask, empty wash bottle, wash bottle with 5% potassium permanganate in 6 N sulfuric acid, two wash bottles containing barium hydroxide (saturated solution), and a soda–lime trap. The reaction flask was a 100-ml., three-necked, round-bottomed flask fitted with a pressure-equalizing dropping funnel and magnetic stirring bar. The train was flushed with nitrogen for 2 hr. prior to filling the barium carbonate collection bottles with saturated barium hydroxide solution. In the reaction flask were placed 0.500 g. (0.00280 mole) of 5-phenylpentanoic-x-^{14}C acid, 1.8 ml. (3.3 g., 0.034 mole) of concentrated sulfuric acid, and 30 ml. of reagent chloroform. Freshly prepared 1.23 M hydrazoic acid (2.7 ml., 0.0033 mole) and 10 ml. of reagent chloroform were placed in the pressure-equalizing dropping funnel. The reaction flask was placed in an oil bath at 45°, and the system was flushed with nitrogen for 0.5 hr. No barium carbonate collected; therefore, the hydrazoic acid was slowly added to the 5-phenylpentanoic-x-^{14}C acid over a 45-min. period. The heating was continued for 2.0 hr.

The wash bottle containing the barium carbonate was isolated from the rest of the train by pinchcocks, taken out of the train, and transferred to a drybox filled with carbon dioxide free nitrogen. The barium carbonate (0.469 g., 85%) was collected by suction filtration, washed with filtered carbon dioxide free distilled water, washed with filtered reagent acetone, and dried at 25° (0.1 mm.).

The chloroform of the reaction mixture was removed under reduced pressure and the reaction products

were made strongly basic with 40% sodium hydroxide. Benzoyl chloride (1.0 ml.) was added, and the resulting white precipitate was filtered. A single recrystallization from ethanol yielded 0.0652 g. (9%) of the benzamide of 4-phenyl-1-aminobutane-x-^{14}C, m.p. 83.0–83.7° (lit.[37] m.p. 83.5°).

Schmidt Degradation of Succinic-x-^{14}C Acid (XVIII). Succinic-x-^{14}C acid (XVIII, 0.1002 g.), m.p. 186.0–186.8°, was added to 0.2397 g. of succinic acid, m.p. 186.4–187.2°. The mixture was dissolved in a minimum amount of hot, filtered acetone and the acetone was removed under reduced pressure. Diluted succinic-x-^{14}C acid was obtained, m.p. 186.0–187.0° (lit.[33] m.p. 184.5–185.0°).

In an apparatus identical with that described above for the degradation of 5-phenylpentanoic-x-^{14}C were placed 0.175 g. (0.00148 mole) of the diluted succinic-x-^{14}C acid, 1.8 ml. (3.3 g., 0.034 mole) of concentrated sulfuric acid, and 30 ml. of reagent chloroform. A solution made from mixing 2.0 ml. (0.0034 mole) of 1.7 M hydrazoic acid in chloroform with 10 ml. of reagent chloroform was placed in the pressure-equalizing dropping funnel. The remainder of the procedure followed that outlined for the degradation of 5-phenylpentanoic-x-^{14}C acid, the hydrazoic acid being added to the succinic-x-^{14}C acid over a 1.25-hr. period, and heating was continued for 3.0 hr. The yield of carbonate was 0.210 g. (72%).

1,2-Diaminoethane-x-^{14}C (XIX) was isolated as the dibenzamide, 0.0635 g. (16%), m.p. 250.8–251.1° (lit.[38] m.p. 249°).

Oxidation of 5-phenyl-5-oxopentanoic-x-^{14}C acid semicarbazone (XVI), obtained from the oxidation of 1-phenylcyclopentene-x-^{14}C, to benzoic-α-^{14}C acid (XVII) was accomplished using alkaline potassium permanganate. 5-Phenyl-5-oxopentanoic-x-^{14}C acid semicarbazone (XVI, 0.500 g., 0.00200 mole), 0.8 g. (0.0075 mole) of sodium carbonate, 4.0 g. (0.025 mole) of finely powdered potassium permanganate, and 500 ml. of water were placed in a 100-ml., round-bottomed flask fitted with a reflux condenser. The solution was heated at the reflux temperature of the mixture for 4.0 hr., cooled, acidified with 6 N sulfuric acid, and refluxed for 1.0 hr. Enough sodium bisulfite was added to remove excess manganese dioxide. Benzoic acid was isolated by continuous extraction of the colorless reaction mixture with ether. Recrystallization of the crude acid obtained from the ether extract from water afforded 0.192 g. (79%) of benzoic-α-^{14}C acid (XVII), m.p. 122.0–122.7° (lit.[35] m.p. 122.4°).

Degradation of 1-Chlorocyclopentene-1-^{14}C (XIV). A. Hydrolysis. About 25 ml. of 75 vol. % sulfuric acid and 2.969 g. (0.0290 mole) of diluted 1-chlorocyclopentene-1-^{14}C (1.548 g. of 1-chlorocyclopentene-1-^{14}C (XIV) diluted to 2.969 g. with 1-chlorocyclopentene) were placed in a 100-ml., round-bottomed flask fitted with a magnetic stirring bar. The mixture was stirred for 1.25 hr. at room temperature. Initially there were two phases; the second disappeared after about 45 min. The reaction mixture was neutralized by adding 40% sodium hydroxide dropwise. The neutral solution was continuously extracted with

(35) J. Timmermans, "Physico-Chemical Constants of Pure Organic Compounds," Elsevier Publishing Co., New York, N. Y., 1950, p. 480.
(36) I. Heilbron, "Dictionary of Organic Compounds," Vol. IV, Oxford University Press, New York, N. Y., 1953, p. 186.
(37) Reference 36, Vol. I, p. 74.
(38) N. D. Cheronis and J. B. Entriken, "Semimicro Qualitative Analysis," T. Y. Crowell Co., New York, N. Y., 1947, p. 402.

ether, and the ether extract was dried successively over anhydrous sodium sulfate and Drierite. Most of the ether was removed through the 20-cm. Heli-Pak column. The cyclopentanone was flash distilled under reduced pressure (5 mm.) into a Dry Ice trap. The yield of crude cyclopentanone was 1.82 g. (75%).

B. 1-Phenylcyclopentene-1-^{14}C from Cyclopentanone 1-^{14}C (XIII). In a 200-ml., three-necked, round-bottomed flask fitted with a pressure-equalizing dropping funnel, magnetic stirring bar, and dry-nitrogen inlet was placed 72 ml. (0.058 mole) of 0.81 M phenyllithium solution[32] in ether. To this solution, cooled in an ice bath, was added dropwise 1.82 g. (0.0216 mole) of cyclopentanone-1-^{14}C (XIII). After the addition was completed, the reaction products were poured into water and neutralized with 3 N sulfuric acid. The ether layer was separated, washed once with water, and dried over anhydrous sodium sulfate. The ether was distilled through the 20-cm. Heli-Pak column, and 25 ml. of 90% formic acid was added to the residue. The formic acid solution was stirred for 2.0 hr. and poured into 10 ml. of water. 1-Phenylcyclopentene-1-^{14}C, which appeared as a second phase during the dehydration, was separated with the aid of pentane; the aqueous layer was extracted twice with pentane. The combined pentane extracts were washed three times with water and dried over anhydrous calcium chloride. The pentane was removed through the 20-cm. Heli-Pak column, leaving 2.98 g. (96%) of 1-phenylcyclopentene-1-^{14}C.

C. Oxidation of 1-Phenylcyclopentene-1-^{14}C to 5-Phenyl-5-oxopentanoic-5-^{14}C Acid Semicarbazone (XVIII). The method was as described for the oxidation of 1-phenylcyclopentene-x-^{14}C (XV). 1-Phenyl-cyclopentene (2.98 g., 0.0207 mole) and 50 ml. of Spectrograde isooctane were added to a pre-equilibrated (30°) solution of potassium permanganate (13.2 g., 0.0835 mole) dissolved in 300 ml. of pH 7 phosphate buffer solution (prepared from 105 ml. of 0.128 M carbonate-free sodium hydroxide solution and 6.80 g. of potassium dihydrogen phosphate diluted o 200 ml.). 5-Phenyl-5-oxopentanoic-5-^{14}C acid semicarbazone (XXVII, 2.33 g., 45%), m.p. 213–215° dec. (lit.[34] m.p. 212–213°), was obtained. Since the cyclopentanone-1-^{14}C (XIII) and 1-phenylcyclopentene-1-^{14}C were not carefully purified, it is more correct to base the yield of semicarbazone on 1-chlorocyclopentene-1-^{14}C (XIV). Accordingly, the over-all yield was 32%.

D. Oxidation of 5-Phenyl-5-oxopentanoic-5-^{14}C Acid to Benzoic-α-^{14}C Acid. The method was as employed for the oxidation of 5-phenyl-5-oxopentanoic-x-^{14}C acid (XVI). 5-Phenyl-5-oxopentanoic-5-^{14}C acid (XXVIII, 1.000 g., 0.00401 mole), sodium carbonate (1.6 g., 0.015 mole), potassium permanganate (8.0 g., 0.05 mole), and 100 ml. of water afforded 0.406 g. (83%) of benzoic-α-^{14}C acid (XXIX), m.p. 122.2–122.8° (lit.[35] m.p. 122.4°).

1-Chlorocyclohexene. 1-Chlorocyclohexene was prepared from cyclohexanone and phosphorus pentachloride by the method of Mousseron and Jacquier[29] in yields varying from 40 to 60%. The cyclohexanone-2-^{14}C (I) which was used in preparation of C^{14}-labeled 1-chlorocyclohexene was obtained from the Radiation Laboratory of the University of California on allocation by the U. S. Atomic Energy Commission.

Coupling Reactions of 1-Chlorocyclohexene with Phenyllithium. The procedure generally followed those described for the preparation of 1-phenylcyclopentene-x-^{14}C (XV). No more than 10% yields of 1-phenyl-cyclohexene were obtained when the reaction was carried out at 100° as previously reported.[17] Biphenyl contaminated the coupling product. The biphenyl need not arise from the 1-phenylcyclohexene,[17] however, since it is a by-product in the preparation of phenyllithium. The yield of 1-phenylcyclohexene is improved by conducting the reaction at 150°. The ^{14}C-labeled 1-chlorocyclohexene (II and III, 10.6 g., 0.100 mole) when heated at 150° with 250 ml. (0.25 mole) of 1 M phenyllithium in ether afforded a 28.5% yield of 1-phenylcyclohexene-x-^{14}C. An infrared analysis of the product showed that biphenyl was a minor contaminant.

1-Phenylcyclohexene with 2,4-Dinitrobenzenesulfenyl Chloride. A. 1-Phenylcyclohexene (0.95 g., 0.0060 mole) and 1.40 g. (0.0060 mole) of 2,4-dinitrobenzene-sulfenyl chloride were dissolved in 25 ml. of dry acetic acid. After 3 days, 0.81 g. of yellow crystalline product was separated by filtration. The product melted at 119–123° with evolution of gas and resolidification. The new product melted near 140°. The solid product and the mother liquors were recrystallized three times from acetic acid and once from ethanol-chloroform; yellow needles (1.18 g., 55%), m.p. 140–141.5°, were obtained.

B. 1-Phenylcyclohexene (3.5 g., 0.022 mole) and 3.8 g. (0.016 mole) of 2,4-dinitrobenzenesulfenyl chloride were dissolved in 75 ml. of glacial acetic acid. The solution was allowed to stand on the steam bath for 45 min., then an excess of water was added and the oil which formed was allowed to solidify. The supernatant liquid was decanted and the product was recrystallized from acetic acid and from ethanol-chloroform. Pure 1-phenyl-2-(2,4-dinitrobenzene-mercapto)cyclohexene (5.0 g., 86%), m.p. 139.5–140.5°, was obtained. This compound was sensitive to air oxidation and to light and slowly decomposed upon standing.

Anal. Calcd. for $C_{18}H_{16}N_2O_4S$: C, 60.66; H, 4.53; N, 7.86; S, 9.00. Found: C, 60.87; H, 4.48; N, 8.00; S, 8.91.

Oxidation of 1-Phenyl-2-(2,4-dinitrobenzenemercapto)-cyclohexene to Benzoic Acid. A. With Chromic Anhydride. 1-Phenyl-2-(2,4-dinitrobenzenemercapto)-cyclohexene (0.69 g., 0.00195 mole) was added to 2.4 g. of chromic anhydride, 50 ml. of acetic acid, 5 ml. of water, and 10 ml. of concentrated sulfuric acid. The mixture was refluxed for 30 min., cooled, poured into 400 ml. of water, and the whole was extracted with 250 ml. of ether. The ether solution was washed with water and extracted with 10% sodium hydroxide solution. The basic extract was acidified with dilute sulfuric acid and extracted with ether. On evaporation of the solvent there was obtained 115 mg. of crude benzoic acid. One recrystallization from water followed by vacuum sublimation at 100° and 10 mm. gave 0.058 g. (25%) of pure benzoic acid, m.p. 121.5–123° (lit.[35] m.p. 122.4°).

In two similar attempts, the above results could not be reproduced and the benzoic acid was heavily contaminated with a yellow compound that could not be separated either by recrystallization or sublimation.

B. With Sodium Permanganate. To 0.920 g. (0.0026 mole) of 1-phenyl-2-(2,4-dinitrobenzenemercapto)cyclohexene was added 1.0 g. of sodium hydroxide and 17.0 g. of sodium permanganate trihydrate in 125 ml. of pyridine and 10 ml. of water. The mixture was refluxed for 1 hr., the excess permanganate was reduced with a saturated solution of sodium sulfite, and the manganese dioxide was removed by filtration. The filter cake was washed with dilute sodium hydroxide and the combined filtrates were evaporated almost to dryness. The residual basic solution was extracted with ether, acidified with dilute sulfuric acid, and extracted with ether. The solvent from the second ether extract was removed through a semimicro column, and the residue was heated for several hours on the steam bath with 2 g. of tin and 10 ml. of concentrated hydrochloric acid. The mixture was poured into water and extracted with ether. The ether extract was washed with water and dried over anhydrous magnesium sulfate, and the solvent was evaporated through a semimicro column. The residue was dissolved in 10 ml. of hot water, centrifuged, and allowed to crystallize in an ice bath. After one sublimation at 100° (10 mm.), 0.078 g. (25%) of benzoic acid, m.p. 122–123 (lit.[35] m.p. 122.4°), was obtained.

1-Chlorocyclohexene with Sulfuric Acid. 1-Chlorocyclohexene (10.0 g., 0.086 mole) was treated with 100 ml. of 90% sulfuric acid at 50°. After 45 min., the reaction mixture was added to crushed ice and extracted with ether. The organic layer was dried over

anhydrous magnesium sulfate and the solvent was removed through a semimicro column.[27] The residue (6.4 g., 75%) was proved to be cyclohexanone by its infrared spectrum and by formation of a 2,4-dinitrophenylhydrazone, m.p. 161–162° (lit.[39] m.p. 162°), and a semicarbazone, m.p. 164–165° (lit.[39] m.p. 166°).

1-Phenylcyclohexanol. Cyclohexanone (9.8 g., 0.1 mole) was slowly added to 0.15 mole of phenyllithium in 250 ml. of ether. The solution was allowed to reflux for 30 min.; then it was cooled and carefully treated with water. The organic layer was washed three times with water, and the ether was evaporated on the steam bath. The residue was dissolved in ligroin and allowed to stand overnight in the refrigerator. Pure 1-phenylcyclohexanol (12.1 g., m.p. 61.5–63°) was obtained. The solvent was evaporated from the mother liquors and the residue was recrystallized from ligroin. Three additional grams of 1-phenylcyclohexanol, m.p. 61–62.5°, was obtained. The total yield was 84%.

1-Phenylcyclohexene. 1-Phenylcyclohexanol (5.5 g.) was refluxed for 5 hr. with 24 ml. of 12% sulfuric acid. The product was treated with hexane and water, and the organic layer was washed several times with water and distilled through a semimicro column.[27] 1-Phenylcyclohexene (4.5 g., 91%), with an infrared spectrum identical with that of an authentic sample, was obtained.

(39) R. L. Shriner and R. C. Fuson, "The Systematic Identification of Organic Compounds," 3rd Ed., John Wiley and Sons, Inc., New York, N. Y., 1948, p. 262.

The Mechanism of a Diels–Alder Reaction. I. A Retrodiene Decarboxylation[1]

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The mechanistic problem of Diels–Alder addition is reconsidered and the advantages to be gained from heavy atom kinetic isotope effect studies are indicated. Decarboxylation of the maleic anhydride adduct of α-pyrone is then shown to satisfy applicable criteria for Diels–Alder retrogression: (a) production of cis-1,2-dihydrophthalic anhydride as the kinetically controlled product, (b) adequately first-order kinetics with $\Delta H^* = 33.2$ kcal./mole and $\Delta S^* = 2.69$ e.u., and (c) identification of the lactonic function as the source of 99.3% of the carbon dioxide liberated. The accepted structures of both reactant and product are confirmed but not that of an isomer of the product, the purported 4,5-dihydrophthalic anhydride, here identified as 1,4-dihydrophthalic anhydride. The dipole moment of the reactant (1.34 D.) is consistent with expectation for the endo isomer.

Introduction

The range of mechanism accessible to Diels–Alder addition has been most restricted by the requirement that diene and dienophile geometry be retained.[3] The problem of mechanism is thus transformed into that of the structure of a transition state whose composition has already been set by the observation of second-order kinetics. Both the dilemma and the challenge derive from an inability to deduce this structure by conventional means: the interpolation between a consecutive pair of experimentally defined, similar structures. With no intermediates nor even, as in other multicenter processes, a structurally similar reactant and product,[4] the structure of the transition state must be deduced solely from its kinetic consequences.[5]

(3) For reviews, see (a) Ya. K. Syrkin and I. I. Moiseev, *Usp. Khim.*, 27, 1321 (1958); (b) J. Martin and R. Hill, *Chem. Rev.*, 61, 537 (1961); (c) R. B. Woodward and T. J. Katz, *Tetrahedron*, 5, 70 (1959); (d) J. A. Berson and A. Remanick, *J. Am. Chem. Soc.*, 83, 4947 (1961).
(4) W. von E. Doering and W. Roth, *Tetrahedron*, 18, 67 (1962).