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II. THE POLAR ADDITION OF DBr TO BICYCLO-
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GRADUATE COLLEGE

I. REACTIONS OF CARBETHOXYCARBENE WITH CARBON-HALOGEN BONDS

II. THE POLAR ADDITION OF DBr TO BICYCLO-[2.2.2]-OCTENE

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY
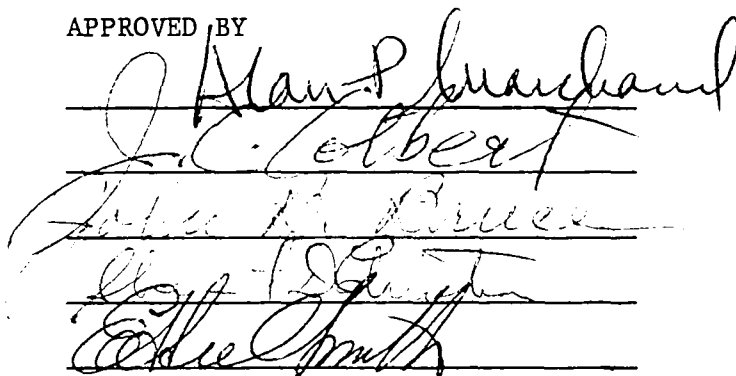
BY

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Norman, Oklahoma

1970

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APPROVED BY

DISSERTATION COMMITTEE

Dedicated to the memory of my high school coach

and chemistry teacher at Terrell High School, Terrell, Texas

Charles E. Lea

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I. REACTIONS OF CARBETHOXYCARBENE WITH CARBON-HALOGEN BONDS

BACKGROUND AND HISTORICAL REVIEW

Ethyl diazoacetate was the first aliphatic diazo compound synthesized[1] and continues to be one of the most extensively utilized compounds of this class of substances. Curtius found that it was formed by treatment of ethyl-α-aminoacetate with nitrous acid.[1] This original synthetic method, with certain procedural modifications,[2] remains the method of choice. In general aliphatic diazo compounds can be made by this method if the amino group is attached to a carbon adjacent to a strong electron withdrawing group.[1,3-7]

Curtius originally postulated a ring structure for ethyl diazoacetate.[1] A chain structure for this and related diazo compounds was proposed by others[8,9] and for many years the cyclic vs. chain nature remained a matter of considerable controversy.[10] Within recent years a significant chemical method has been used to support a chain structure.[11] Thus, tagged (i.e., N^{15}) $NaNO_2$ was used in the preparative procedure and the ethyl diazoacetate formed was subsequently decomposed by reduction to

glycine and ammonia. Analysis of these latter two compounds for N^{15} content revealed values so close to the values expected for a chain structure (i.e., active $N^{15}H_3$, inactive $H_2N^{14}CH_2CO_2Et$) that a ring structure was excluded. Physical evidence by the method of electron diffraction has shown for diazo compounds in general[12] that the nitrogen atoms and the adjacent carbon atom are all in a straight line, as originally shown by Boersch using diazomethane.[13] Ethyl diazoacetate may be represented, therefore, as a resonance hybrid with the following four major contributing forms.
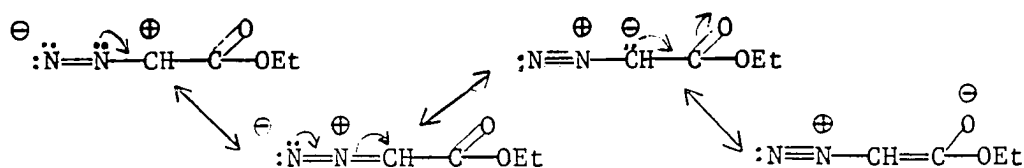
The three member cyclic counter-parts are now recognized as distinctively different compounds and are known as aziridines.[14] They differ from diazoalkanes in both physical and chemical properties.[14]

Quite recently α-diazo carbonyl compounds have been shown to exhibit a distinct conformational preference (usually for the diazo to carbonyl cis form[15,16]). A consideration of conformationally preferred forms has been employed in attempts to rationalize some α-diazo carbonyl reactions.[16,17] Ethyl diazoacetate, however, displays no conformational preference,[16] a fact which discredits previous interpretations that assumed a cis preference.[17]
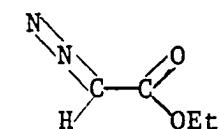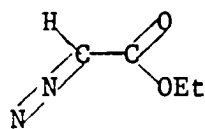
cis conformer   trans conformer

Ethyl diazoacetate has two absorption regions in the U.V. range, i.e., ca. 2500 A^o (major) and ca. 3800 A^o (minor). The excited N_2CHCO_2Et at 2500 A^o is more polar than the ground state and involves $\pi \rightarrow \pi^*$ transition; whereas, the excited N_2CHCO_2Et at 3800 A^o is less polar than the ground state form and involves $n \rightarrow \pi^*$ transition.[18,19] These absorption characteristics are reflected to some extent in quantum yield trends of ethyl diazoacetate photolysis. Thus: (a) the quantum yield decreases with increasing wavelength; (b) at lower wavelengths the quantum yield increases with increased solvent polarity; (c) at higher wavelengths the quantum yield decreases with increased solvent polarity.[19]

The decomposition of ethyl diazoacetate may be brought about by the action of U.V. light, heat (ca. 150°), and by the use of certain metal catalysts ($90-100^o$).[19] Nitrogen is evolved and in photolytic or thermolytic decompositions, the reactive divalent intermediate carbethoxycarbene is formed; whereas, metal catalysis involves carbethoxycarbenoid formation.[20-22] Our interest in ethyl diazoacetate is based upon its utility as a source of these intermediates. In fact it is the only compound ever satisfactorily employed as a precursor to carbethoxycarbene (carbethoxycarbenoid).[23] Our attention will now be focused on these intermediates and the reactions which they undergo.

A carbene is an uncharged species in which carbon has two of its own electrons involved in bonding and with two not involved in bonding. The two non-bonded electrons of carbethoxycarbene may be paired, singlet form, or unpaired, triplet form.
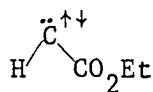
singlet form
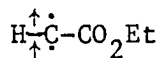
triplet form

Complexing with metal catalysts forms carbethoxycarbenoid. The reactions of these moieties may be conveniently categorized as addition, insertion, miscellaneous, and HX elimination.

THE ADDITION REACTION:

Singlet carbene addition to an unsaturated linkage is generally considered to be a concerted reaction involving no real intermediate.[24] The concerted nature of the process demands that this addition reaction be stereospecific, i.e., the geometrical relationship of the unsaturated linkage is preserved in the cyclic product.[24] Gaspar and Hammond[25] have pointed out that a carbene in the singlet state could theoretically add via a non-concerted biradical mechanism which would almost certainly be somewhat non-stereospecific. In all the carbene literature, however, not a single case has been reported in which a carbene demonstrated to exist in the singlet spin state displayed non-stereospecific addition. Nevertheless, it has been suggested[25] that non-stereospecific addition should not be taken as unequivocal proof that the reacting carbene is a triplet unless it has also been shown that under some other conditions a species of the same composition (i.e., the same carbene but in a singlet spin state) gives stereospecific additions.

Triplet carbene addition is expected to occur as a two step reaction involving a diradical intermediate.[24] As such there is no demand for stereospecificity.[24] Indeed, one expects that in the intermediate, rotation about the bonds would be at least as rapid as the spin inversion needed before formation of the cyclic product.[24] It is theoretically possible for triplet carbene to add stereospecifically if (via

the interaction of solvent cage effects, etc.) the required spin inver-

sion in the intermediate occurs prior to bond rotation.[26] In all the

carbene literature, however, not a single case has been reported in

which a carbene demonstrated to exist in the triplet spin state has been

shown to display stereospecific addition. Some additions, however,

thought to involve triplet carbene are highly stereoselective.[27]

Although in general carbenoids display many of the chemical pro-

perties of the corresponding carbene, relatively little is known about

their energetic and structural features.[24] They may not even possess a

free, non-metal-complexed, divalent carbon atom.[24] It follows, therefore,

that at the present time carbenoid additions are less subject to mechanis-

tic interpretation and correlation.

The addition of carbethoxycarbene to 2-butene, 4-octene, and stil-

bene in the liquid phase has been shown to proceed stereospecifically

cis.[28,29] These results strongly suggest that singlet carbethoxycarbene

is the reactive species. Unequivocal proof of this has not been provided

as yet, however, since gas phase studies have not been made (stereospeci-

fic addition in the gas phase provides unequivocal proof of singlet carbene[25]),

and deliberate efforts to form and observe non-stereospecific triplet car-

bethoxycarbene (presumably the ground state species) additions have not

been reported.

If the olefin attacks the empty p orbital of carbethoxycarbene,

the transition state may be represented:
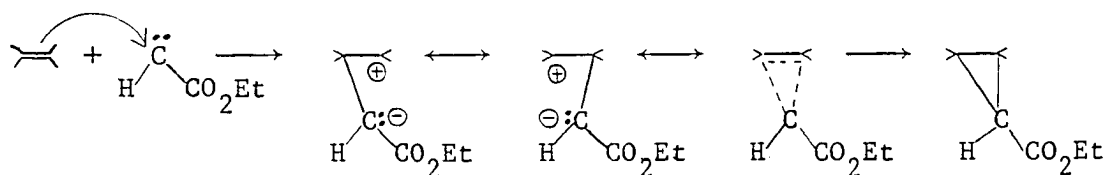
transition state

This representation of the transition state is in accord with the obser-
vation that the most heavily alkylated olefins generally react with a
given carbene most rapidly.[22] The alkyl substituents stabilize (via in-
duction and/or hyperconjugation) the transition state and thus facilitate
a faster reaction rate.[22]

When exo, endo isomers can be formed the less crowded arrangement
of substituents is preferred.[28] Carbethoxycarbene produced by photolysis
adds to cyclohexene forming exo/endo isomers in a 2/1 ratio. The Cu cata-
lyzed addition of carbethoxycarbenoid forms a 17/1 isomeric mixture.[21]
The increased discrimination in the latter case in favor of the less hin-
dered product is presumably due to the greater bulk and lower reactivity
of the carbenoid[21] (as compared to the free carbene produced by photolysis).
This lower reactivity or weaker electrophilic character is further evi-
denced in the inability of carbethoxycarbenoid to add to aromatic systems
and to insert into C-H bonds.[21]

Other olefins to which carbethoxycarbene (carbethoxycarbenoid) has
been successfully added include: styrene,[30] cyclooctene,[31] 1,1-diphenyl-
ethylene,[32] acenaphthylene,[33] vinyl ethers,[34,35] dihydrofurans and pyrans,[36]
ketene acetal,[37] vinyl acetate,[38] allyl acetate,[39] unsaturated silanes and
germanes,[40] allyl alcohol,[41] allyl chloride,[42] 2-methyl-1,3-butadiene,[43]
cyclopentadiene,[44] 1-phenyl-1,3-butadiene,[45] various 1,3-pentadiene-1-
carboxylic acids,[46] cyclooctatetraene,[47] sabinene,[48] cycloheptatriene,[49]
norbornadiene,[50] cyclopropene,[51] 1,3-cyclohexadiene,[52] cyclopentadiene,[53]
norbornene,[54] 1-heptene,[55] 1-hexene,[55] 1-octene,[55] 1-decene,[55] tetramethyl-
ethylene,[56] 2,3-dimethyl-1-butene,[57] cis 1,2-diphenylethylene,[58] trans 1,2-
diphenylethylene,[59] 2,3-dichloro-1-propene,[60] pinene,[61] porphyrins,[62-64]

and many others. In most cases the stereochemistry of the products has not been elucidated.[65]

Carbethoxycarbene is also known to react with aromatic compounds. Benzene reacts to yield norcardiene carboxylic esters which rearrange to cycloheptatriene carboxylic esters. This reaction was discovered in 1885,[66] but wasn't understood until 1956.[67] A study of the effect of ring substituents revealed that electron releasing substituents facilitate the reaction. The low reaction constant (ρ = -.38) indicated that for this electrophilic aromatic reaction not much charge had developed in the ring at the transition state.[22] The reaction appears to be more sensitive to steric hindrance than polar effects. Addition at the 3,4 bond of toluene accounted for 60% of the isolated cycloheptatriene carboxylic esters, with 35% 2,3 and 5% 1,2 addition.[68] t-Butyl benzene, however, resulted in exclusive 3,4 addition.[68] Methodically increasing the alkyl substitution of the benzene nucleus (xylene,[69] mesitylene,[70] durene,[71] prehnitene[72]) decreases the amount of ring expansion product with subsequent increase in the amount of insertion at the C-H methyl groups. Furthermore, carbethoxycarbene reacts preferentially with 2,3-dimethyl napthalene in the unsubstituted ring (58% vs. 37%).[73]

Carbethoxycarbene has also been added to other aromatic systems such as napthalene,[74] 2,6-dimethylnapthalene,[74] anthracene,[75] pyrene,[75] phenanthrene,[76] indans,[77] furan,[78] benzofuran,[79] thiophene,[80] benzothiophene,[81] fluorenes,[82] and many more.

In addition to the considerable number of olefinic and aromatic C=C reactions with :CHCO$_2$Et, other π bond systems such as -C≡N,[83] -C≡C-,[28] -N=N-,[84] C=S[85] and C=O[86,87] are capable of addition. Even 1,4 addition

to $\diagup C\!\!=\!\!C\!\!-\!\!C\!\!=\!\!O$[88] and $O\!\!=\!\!C\!\!-\!\!C\!\!=\!\!O$[89] systems have been observed although these are extremely rare.

THE INSERTION REACTION:

In the most general sense an insertion reaction is one wherein the overall change is that of "insertion" of a carbene between a bond X—Y.

$$X\!\!-\!\!Y \;+\; :C\diagdown \;\longrightarrow\; X\!\!-\!\!\underset{|}{\overset{|}{C}}\!\!-\!\!Y$$
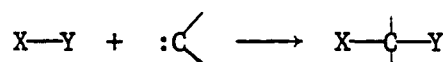
The most widely accepted mechanism for singlet carbene insertion involves a concerted process involving no real intermediate.[90,91]

$$X\!\overset{\uparrow\downarrow}{-}\!Y \;+\; \uparrow\downarrow\!:C \;\longrightarrow\; \begin{array}{c} X\!\text{-}\text{-}\text{-}Y \\ \diagdown \;\; \diagup \\ \diagdown\!\diagup \\ C \\ \diagup\diagdown \end{array} \;\longrightarrow\; X\!\!-\!\!\underset{|}{\overset{|}{C}}\!\!-\!\!Y$$
$$\text{transition}$$
$$\text{state}$$
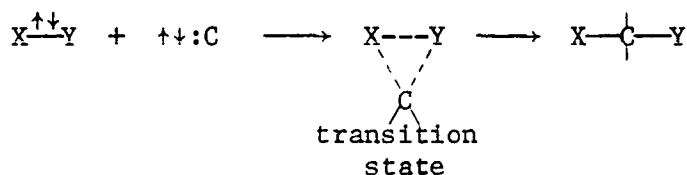
A two step reaction involving a free radical intermediate has also received limited recognition.[92-96]

$$X\!\overset{\uparrow\downarrow}{-}\!Y \;+\; \uparrow\downarrow\!:C\diagdown \;\longrightarrow\; X\!\cdot\uparrow \;+\; \overset{\cap}{\downarrow\uparrow}\!\cdot C\!\!-\!\!Y \;\longrightarrow\; X\!\!-\!\!\underset{|}{\overset{|}{C}}\!\!-\!\!Y$$
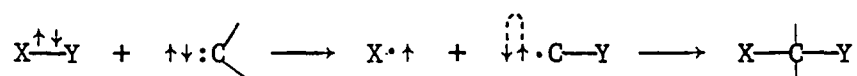
When atoms with lone-pair electrons are present at or near the substrate's reactive site, an ylid mechanism may be operative.[22]

$$X\!\!-\!\!Y\!:\!\uparrow\downarrow \;+\; \uparrow\downarrow\!:C\diagdown \;\longrightarrow\; X\underset{\oplus}{\overset{\ominus}{\text{-}}}Y\!\!-\!\!\overset{\cdots\uparrow\downarrow}{C}\!\!-\!\! \;\longrightarrow\; Y\!\!-\!\!\underset{|}{\overset{|}{C}}\!\!-\!\!X$$
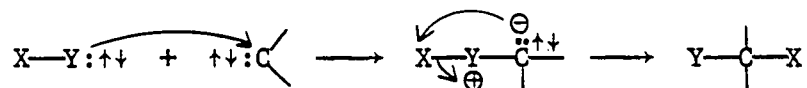
A two step reaction involving free radical intermediates must be postulated (due to the required change in spin) for a triplet carbene.[24,96]

$$X\!\overset{\uparrow\downarrow}{-}\!Y \;+\; \uparrow\!\cdot\!\underset{|}{\overset{|}{C}}\!\cdot\!\uparrow \;\longrightarrow\; X\!\cdot\uparrow \;+\; \overset{\cap}{\downarrow\uparrow}\!\cdot\underset{|}{\overset{|}{C}}\!\!-\!\!Y \;\longrightarrow\; X\!\!-\!\!\underset{|}{\overset{|}{C}}\!\!-\!\!Y$$
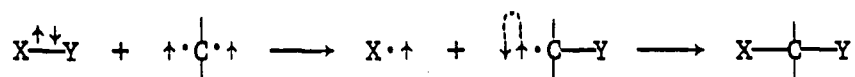
A singlet carbene, $R_2C:$, has an R-C-R bond angle that varies

with the nature of the R substituents. Generally, the angle is within

the region of $110\pm10°$.[97-99] It is more adept at insertion than a triplet

which is more nearly linear.[90] That a singlet is more adept at inser-

tion is due to:[90] (a) a singlet is (with a few exceptions[100]) more ener-

getic than a triplet; (b) since insertion by a singlet is (with a few

possible exceptions[92-95]) a concerted process no change in spin is neces-

sary; (c) a singlet's R-C-R bond angle, $110\pm10°$, is much nearer that, $109°$,

which it is required to have in the reaction product.

Reports of a few reactions that involved carbethoxycarbene inser-

tion into C-H bonds may be found in the literature of long ago.[69-72,101-103]

It was not until 1956, however, when Doering and Knox observed C-H inser-

tion in purely aliphatic hydrocarbons that the reaction received its proper

recognition.[104] Their liquid phase photolysis studies revealed that a pre-

ference sequence of $3°$ C-H > $2°$ C-H > $1°$ C-H was displayed. This discri-

minating ability of carbethoxycarbene contrasted with the completely indis-

criminant behavior of methylene under comparable conditions.[105] Explanations

have been formulated on the basis of a greater E_A and a lesser exothermicity

for the carbethoxycarbene insertion. According to the Hammond Postulate[106]

the greater the exothermicity of a reaction the less the transition state

will resemble the products. Due to the large exothermic character of the

methylene reaction the transition state is not far enough advanced toward

the products in order for C-H bond stretching to be of importance. Car-

bethoxycarbene reaction has less exothermic character, thus, C-H bond

stretching in the transition state is more pronounced. Hence, its rate of

reaction with various C-H bonds reflects the strengths of the bonds being

broken with 3° being most favored and 1° insertion being least favored. This interpretation seems reasonable in view of elementary arguments about delocalization which indicate that the carbethoxy group should stabilize a carbene and as a direct consequence decrease the exothermicity and increase the E_A.[107] These concepts are represented graphically in Fig. 1, below, in which the potential energy of the insertion reaction is plotted as a function of "reaction coordinate."

FIG. 1

REACTION PROGRESS ⟶
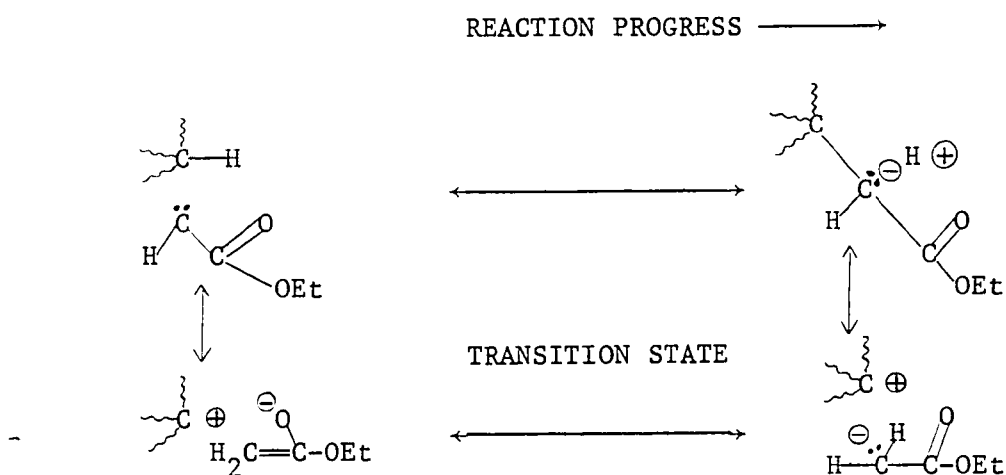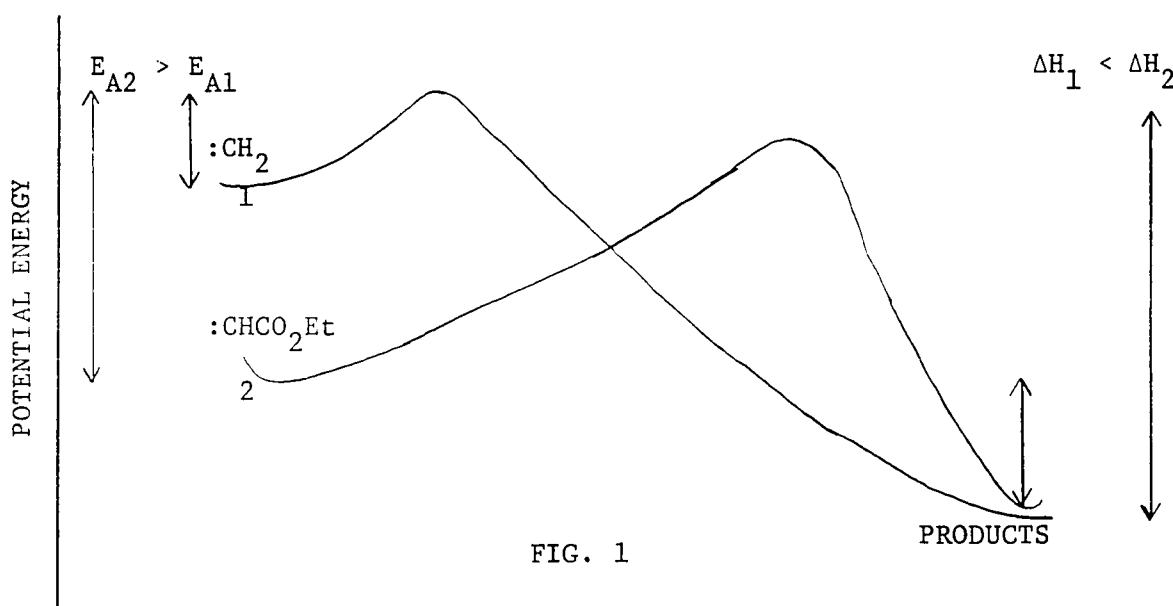
TRANSITION STATE

Support for this concept of the transition state of C-H insertion by carbethoxycarbene was obtained by R. R. Sauers and R. J. Kiesel in their study of nortricyclene.[108] They found the bridgehead position to be particularly unreactive and attributed this to the unfavorable geometry of the dipolar contributors to the transition state

$$(\nearrow \oplus \overset{\ominus}{:}\overset{..}{C}HCO_2Et \longleftrightarrow \nearrow \oplus \quad CH_2=C\overset{\overset{\ominus}{O}}{\underset{OEt}{}} \quad , \quad i.e., \quad non\text{-}planar \nearrow \oplus \;).$$
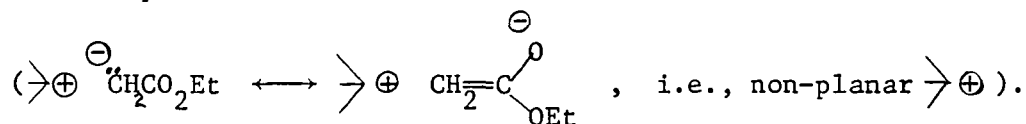
J. D. Collins has studied the liquid phase unsensitized and benzophenone sensitized reaction of carbethoxycarbene with methyl cyclopentane.[96] Of the various isomers formed the trans-1,2 and cis-1,2 insertion products were of particular interest. The trans/cis ratio for the unsensitized insertion was 1.27. The trans preference was attributed to a steric influence which retarded the development of the 3-centered transition state leading to cis C-H insertion by singlet carbethoxycarbene. The sensitized reaction, postulated to involve triplet carbethoxycarbene, proceeded with a diminished steric influence by the substrate on the reaction course. Thus, the trans/cis ratio was only 1.16 or 1.04 (depending on the amount of benzophenone used).

Collins has also studied the stereochemistry of carbethoxycarbene insertion into the 3° C-H bond of cis 1,2-dimethylcyclohexane.[96] The unsensitized insertion occurred with complete retention of stereochemistry, suggesting singlet carbethoxycarbene; whereas, the sensitized insertion was non-stereospecific, suggesting triplet carbethoxycarbene.

Reactions involving overall insertion of the :CHCO$_2$Et moiety into other linkages has received surprisingly little attention, though isolated reports may be found involving the bonds C-N,[109] C-O,[110,111] O-H,[41,112]

C-Cl,[42,113-115] C-Br,[42,113-116] C-I,[117] N-H,[1,118] S-Cl,[119] and C-S.[120]

It was the C-Halogen bond which attracted our attention in particular. Polyhalo compound reactions with carbethoxycarbene received its major attention in the 1950's. Gutsche reported the thermal liquid phase reaction of $:CHCO_2Et$ with benzal chloride to yield ethyl-α-chlorocinnamate, with none of the presumed initial C-Cl insertion adduct isolated.[111]

An extensive study was made by Urry and Wilt.[114,121] Their liquid phase photolytic reactions with CCl_4, CH_2Br_2, CBr_2Cl_2, $CHBr_3$, CH_2Cl_2, $CHCl_3$, CH_2ClBr, $CHCl_2Br$, CCl_3Br, $CHClBr_2$, and Cl_2CHCO_2Me resulted mainly in the formation of C-X insertion products (8-30% yields). Significant facts having a bearing on possible mechanisms included: (a) both chlorine and bromine appeared as α-substituents in the products, but chlorine appeared as the α-substituent when bromine was present; (b) the reactions were of zero order; (c) substances which must have resulted from free radical processes (such as hexahaloethanes) were occasionally found; (d) diphenylamine (a free radical scavenger) inhibited the reaction rate only slightly. The ylid mechanism depicted below was proposed as the one best in accord with these and other experimental facts.[122]
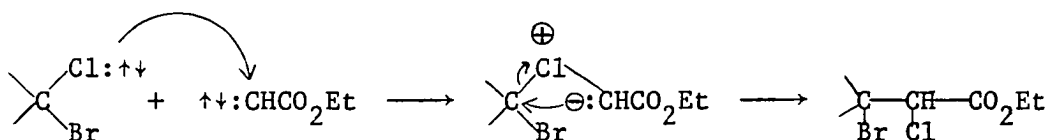
Their postulate concerning the C-Cl insertion preference was based on the greater electronegativity of the Cl atom. Thus, the electrophilic carbethoxycarbene might be expected to complete its electronic shell octet by seeking a reaction site where the electron density is the highest. This interpretation appears inadequate, however, in view of some observations

by others[123] as well as results from our study[124] indicating a prefer-ence for C-Br bond cleavage in simple monohaloalkane systems. Various competing free radical sequences were proposed to account for the small amounts of other products (i.e., hexahaloethanes, etc.).

In an effort to obtain mechanistic information concerning the reactions of carbenes with polyhalomethanes, Bilow[115] photolyzed methyl diazoacetate in a solution of optically active methyl chlorobromoacetate (69% active, α_D^{33} = -10.3°). The product was optically active methyl-α-chloro-α'-bromosuccinate (α_D^{33} = -2.4°). The fact that optically active product was obtained lends support to the concerted nature of the C-X insertion process as suggested by the aforementioned results of Urry and Wilt. Contrariwise, it makes unlikely (in the absence of solvent cage effects) the interpretation that this reaction proceeded by a free radical mechanism. Unfortunately, the configurational relationship between opti-cally active methyl chlorobromoacetate and the methyl-α-chloro-α'-bromo-succinate is not known and this restricts mechanistic deductions. An in-depth reinvestigation of this reaction underway in the laboratory of A. P. Marchand will hopefully provide new insight into the reaction mechanism.

The most extensive study of monohalo compounds has been made by Dyakonov.[123] All of his work, however, has involved metal catalysts and hence carbethoxycarbenoid rather than the free carbene. Excellent yields of C-Br and C-I insertion products were obtained with various simple allyl halide systems. No cyclopropanes were obtained from the allyl bromides and iodides; whereas, addition of carbethoxycarbenoid to the double bond competed effectively with insertion into the C-Cl bond of allyl chlorides.[123] Phillips established that these reactions sometimes

form products with a rearranged skeleton.[113] Thus, 3-chloro-1-butene

reacted to form 10% CH_2=CH-CH-CH-CO_2Et plus 40% CH_3CH=CH-CH_2-CH-CO_2Et.
CH_3ClCl

Neither rearrangement of reactant nor products occurred under the re-

action conditions; hence, the skeletal rearrangement must have occurred

in the intermediate. No skeletal change occurred in the sluggish re-

action of _trans_ 1,3-dichloropropene indicating a direct C-Cl insertion

to yield ClCH=CH-CH_2CH-CO_2Et. This same exclusive product was obtained
Cl

in the fast reaction of 3,3-dichloropropene indicating complete rear-

rangement. An $S_{N2'}$ mechanism involving intermediate ylid formation seems

probable.

$$CH_2=CH-\overset{\overset{H}{|}}{\underset{\underset{\cdot\cdot}{|}}{C}}-Cl \; + \; \overset{\cdot\cdot}{C}H-\overset{\overset{O}{||}}{C}-OEt \qquad CH_2=CH-\overset{\overset{H}{|}}{\underset{\underset{\ominus\;\;\;\;\;\;:CH}{\nearrow}}{C}}-Cl^{\oplus} \qquad EtO-\overset{\overset{O}{||}}{C}-\underset{\underset{Cl}{|}}{C}H-CH_2-CH=CHCl$$
$$\overset{|}{C}O_2Et$$
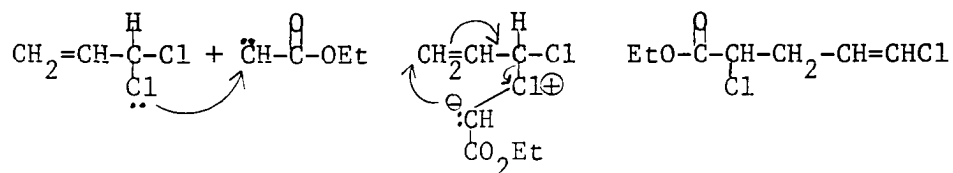
Most benzylic monohaloalkanes have been reported to yield little

if any C-X insertion product with carbethoxycarbenoid. These reactions

undoubtedly involve complex radical chain processes and feature facile

aryl group migrations.[125]

Simple aliphatic saturated monohaloalkanes have been reported by

Dyakonov to undergo no C-X insertion with carbethoxycarbenoid.[117] Wilt[121]

reported that _tert_-butyl chloride failed to react with carbethoxycarbene;

whereas, Franzen[126] reported trace amounts of C-X insertions by carbeth-

oxycarbene.

One of the original aims of our investigation of simple alkyl

halides was to study the stereochemistry of C-Br insertion. For this

purpose the preparation of 2-bromobutane was proposed as depicted in

Scheme 1.
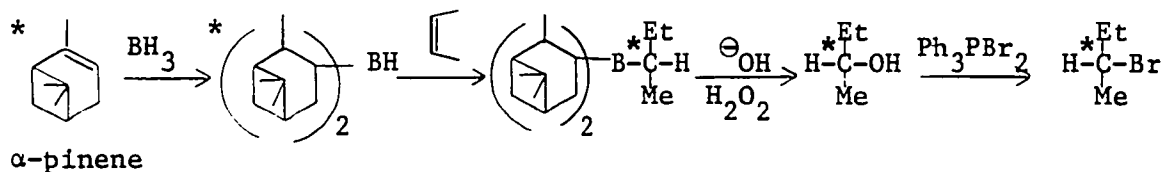
Scheme 1

This substrate in reaction with carbethoxycarbene a priori might be expected to undergo C-Br insertion to give either optically inactive or optically active product. A determination of which would yield valuable mechanistic information about the insertion process. Thus, optically inactive product would strongly implicate a stepwise process involving an intermediate incapable of sustaining optical activity such as a free carbonium ion, radical, or carbanion. On the other hand, optically active product would suggest a concerted process. A distinction between retention or inversion could then be made via a subsequent degradation scheme involving conversion of the α-bromoester product to 3-methyl-1-pentanol (a compound of known configurational relationship[127]).

Efforts in this direction were soon jeopardized when it became apparent that initial liquid phase photolysis of ethyl diazoacetate in 2-bromobutane yielded only a trace of desired product. A similar lack of any but minute C-Br insertion was observed with ethyl bromide, isopropyl bromide, tert-butyl bromide, ethyl chloride, isopropyl chloride, tert-butyl chloride, 2-chlorobutane, ethyl iodide, isopropyl iodide, tert-butyl iodide, and 2-iodobutane. Neither the alteration of such variables as temperature, dilution, and wavelength nor the use of sensitizer, catalyst, and various solvents was effective in increasing the amount of C-Br insertion (see Results and Discussion Section).

THE MISCELLANEOUS REACTIONS:

The carbethoxycarbene (carbethoxycarbenoid) moiety may be represented in a 1,3-dipolar resonance form (assuming a singlet state[128]).

$$:CH-\overset{\overset{O}{\parallel}}{C}-OEt \longleftrightarrow \oplus CH=\overset{\overset{\ominus O}{\parallel}}{C}-OEt$$

Therefore, a priori, it might be expected that this carbene (carbenoid) could react in a manner characteristic of 1,3-dipolar species, i.e., 1,3-dipolar addition to a multiple bond; the reaction type so well recognized, characterized, and developed by Rolf Huisgen and co-workers.[87]

$$
\begin{array}{c}
\overset{\ominus O}{\underset{a}{\big|}}\overset{}{\underset{\parallel}{}}\text{C-OEt} \\
\underset{b}{\big|}\overset{}{\underset{\oplus C-H}{}}
\end{array}
\longrightarrow
\begin{array}{c}
\overset{O}{\underset{a}{\big|}}\text{C-OEt} \\
\underset{b}{\big|}\text{C-H}
\end{array}
$$
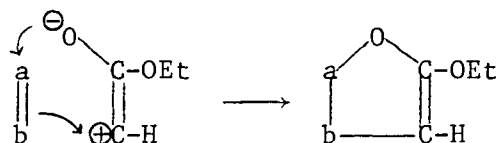
Only rarely, however, has this type of reaction been observed for :CHCO$_2$Et.[129] Carbethoxycarbenoid formed by the CuSO$_4$ catalyzed ethyl diazoacetate decomposition reacts with such acetylenes as tolan and 1-phenylpropyne to form 5-substituted-2-ethoxy-4-phenylfurans.[130] These furans are not formed, however, if Cu catalyst is used nor under purely thermal conditions.[130-133] Nitriles such as benzonitrile, acetonitrile, and phenylacetonitrile form 2-substituted-5-ethoxyoxazoles under both thermal and CuSO$_4$ catalyzed conditions but not photochemically.[83,134] It has been suggested that the mesomerism of the carboxylic ester, which tends to oppose the 1,3-dipolar activity, is responsible for its limited ability to undergo 1,3-dipolar reactions.[87]

$$:CH-\overset{\overset{O}{\parallel}}{C}-\ddot{O}Et \longleftrightarrow :CH-\overset{\overset{\ominus O}{\parallel}}{C}=\underset{\oplus}{\ddot{O}Et}$$
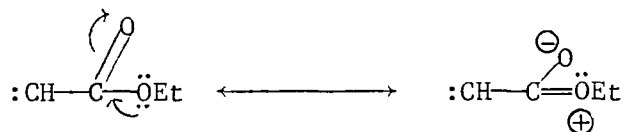
Two carbethoxycarbenoids may unite (or more probably carbethoxycarbenoid plus N$_2$CHCO$_2$Et) to form diethyl fumarate. Carbethoxycarbene

itself, however, is incapable of such dimer formation since none is

formed in photolytic or un-catalyzed pyrolyses.[19,135]

Carbonyl compounds readily react with carbethoxycarbene (car-

bethoxycarbenoid) to initially form a zwitterion or 1,3-dipole which may

react further in a variety of ways. Enolizable compounds such as acetone

and cyclohexanone prefer to react intramolecularly by proton removal to

form an enol ether. The zwitterion may also collapse to form substituted

glycidic esters or undergo 1,3-dipolar cycloaddition with C=O to form

substituted dioxalanes.[87,136]
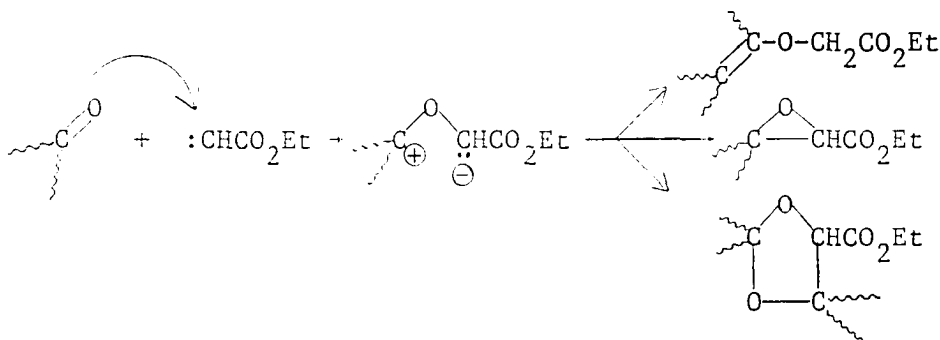
A reaction that a priori might be expected is intramolecular in-

sertion to form a 5-member lactone;

however, this intramolecular insertion reaction has not been reported in

the literature. Rando attributed this to the conformational preference

(carbonyl cis to diazo) of the carbene precursor, ethyl diazoacetate.[17]

This is essentially a steric argument. Thus, upon generation, the carbene

center and the alkoxy group are not in close proximity; therefore, reaction

occurs between the carbene and a molecule comprising the solvent shell.

Ethyl diazoacetate is now known to display no conformational preference,[15,16] a fact which discredits Rando's interpretation. Another factor that may be involved is the expected C-H insertion deactivation due to the β-electron withdrawing oxygen atom.[137] The first report of intramolecular insertion of an alkoxycarbonyl carbene (carbo-tert-butoxycarbene) was in 1967.[138] Since then only one other report of intramolecular alkoxycarbonyl carbene insertion has appeared.[139]

Another previously unreported type of intramolecular reaction, i.e., Wolf Rearrangement to ethoxyketene appeared recently also.[112] Thus, liquid phase N_2CHCO_2Et photolysis in isopropanol formed $EtO-CH_2-\overset{\displaystyle O}{\overset{\|}{C}}-O-\overset{\displaystyle CH_3}{\underset{}{CHCH_3}}$ via isopropanol attack on ethoxyketene. This observation of appreciable initial intramolecular reaction (i.e., rearrangement) was attributed to a decreased reactivity of the polar solvent as compared to hydrocarbons, etc. Rearrangement may, however, occur in non-protic solvent; photolysis of methyl diazoacetate in benzene involves appreciable carbene (the singlet form[140]) rearrangement to methoxyketene as depicted in Scheme 2.[141]

a mixture of 4
stereoisomers, 55% yield
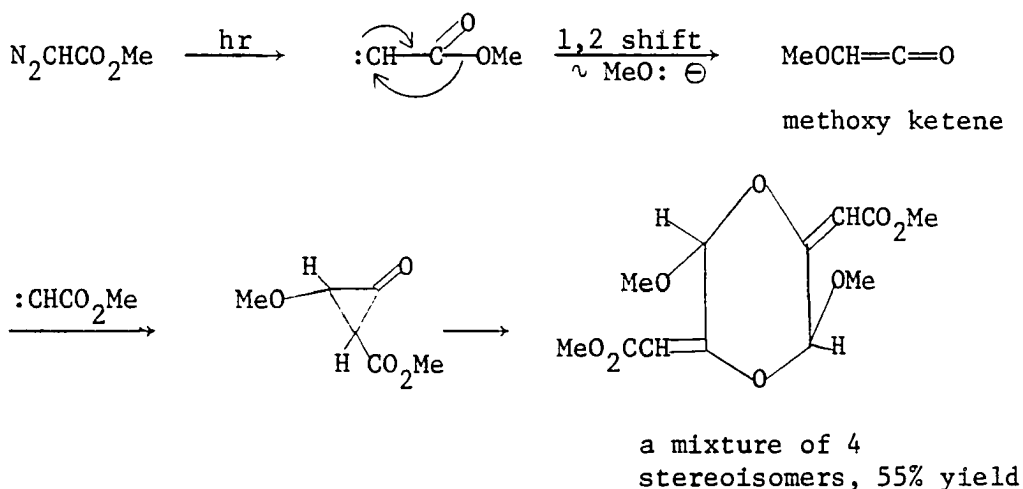
Scheme 2

HX ELIMINATION: (X = $-NR_2$, $-OR$, $-OAr$, $-Cl$, $-Br$, $-I$)

There are widely scattered and isolated reports in the chemical literature of reactions in which a compound R-X reacts with carbethoxy-carbene (carbethoxycarbenoid) to form XCH_2CO_2Et. Although the available evidence indicates the probability of diverse mechanistic pathways, these reactions at least share some formal similarity. This formal similarity has, however, thus far not received general recognition. The following reaction tabulation represents the results of a comprehensive survey.

It has been suggested that NR_3,[22,109] ROR,[186,187] and simple alkyl halides[137] undergo β-elimination via an intermediate ylid.
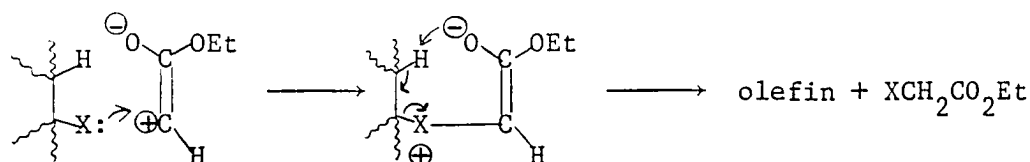
X = $-NR_2$, $-OR$, $-Br$, $-Cl$

This mechanism cannot be operative, however, with methyl aryl ethers since they possess no hydrogen on the alkyl β to the heteroatom. The fate of the methyl group is unknown and no mechanism has been proposed to account for the observed $ArOCH_2CO_2Et$ product.[190] One apparent possibility involves ylid formation followed by α-elimination.
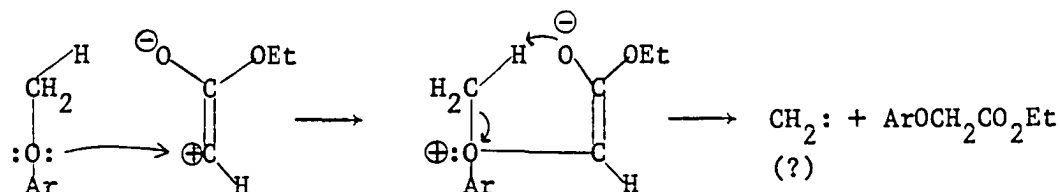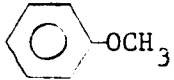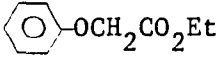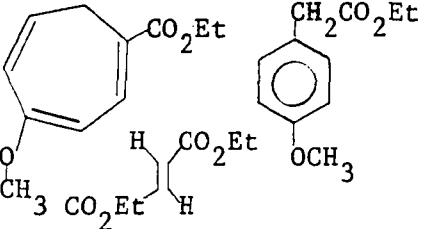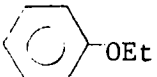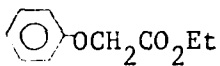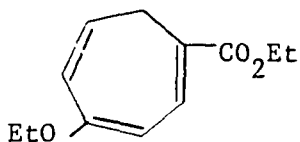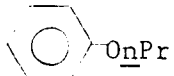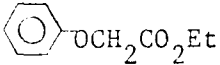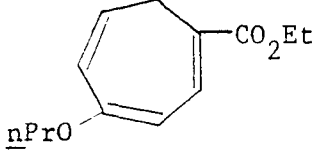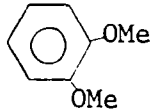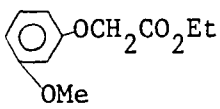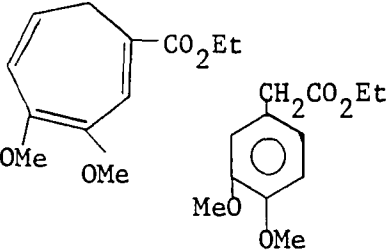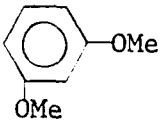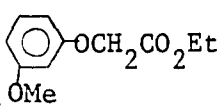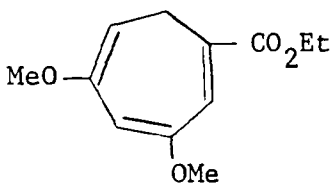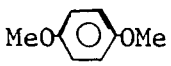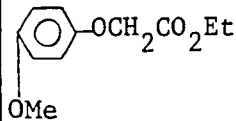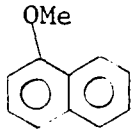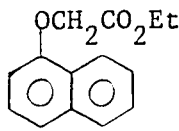
The methyl alkyl ethers allow an interesting competition. Thus,
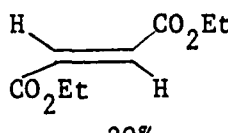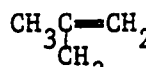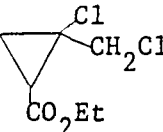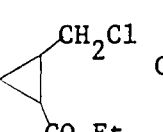
Table 1

SUBSTRATE CLASS	SUBSTRATE	METHOD	XCH_2CO_2R PRODUCT	OTHER PRODUCTS	REF.
R-N-R R	Et-N-Et Et	hr	Et-N-CH$_2$CO$_2$Et Et	Et-N-CHCH$_2$CO$_2$Et 45% Et CH$_3$ Et-N-CH$_2$CH$_2$CH$_2$CO$_2$Et Et	109
R-O-R	Et-O-Et	hr	EtO-CH$_2$CO$_2$Me	EtO-CHCH$_2$CO$_2$Me CH$_3$ EtO-CH$_2$CH$_2$CH$_2$CO$_2$Me	186
	$\underline{n}$Bu-O-$\underline{n}$Bu	hr	$\underline{n}$BuO-CH$_2$CO$_2$Me 52%	$\underline{n}$BuO-C$_7$H$_{13}$O$_2$ isomers	186
	$\underline{n}$Bu-O-$\underline{n}$Bu	Δ	$\underline{n}$BuO-CH$_2$CO$_2$Et 9%	$\underline{n}$BuO-C$_8$H$_{15}$O$_2$ 24% isomers CH$_3$CH$_2$CH=CH$_2$ 6%	187 188
	$\underline{n}$C$_7$H$_{15}$-O-CH$_3$	Δ	CH$_3$O-CH$_2$CO$_2$Et 16% $\underline{n}$C$_7$H$_{15}$CH$_2$CO$_2$Et 27%		188
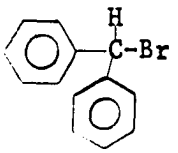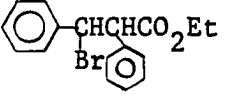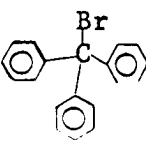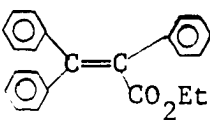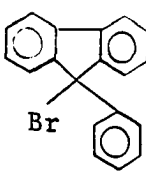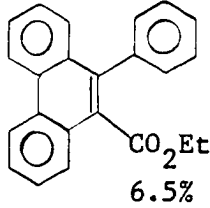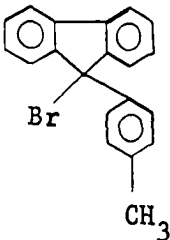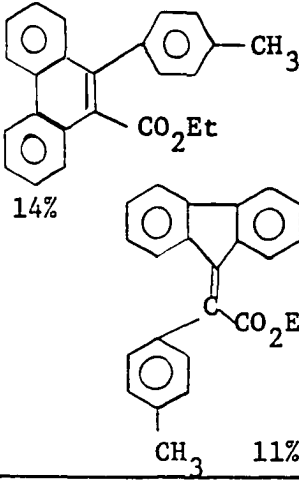
Note: It was necessary to recalculate all literature reported yields to compensate for different methods of calculation used for reported per cent yields, author computational errors, and abstractor's errors. All yields reported herein are uniformly based on the amount of N_2CHCO_2R <u>consumed</u> in the reaction.

SUBSTRATE CLASS	SUBSTRATE	METHOD	XCH_2CO_2Et PRODUCT	OTHER PRODUCTS	REF.
ArOR	OCH_3 (anisole)	Δ	OCH_2CO_2Et 2.5%	cycloheptatriene–CO_2Et, OCH_3; CH_2CO_2Et / OCH_3; OCH_3, CO_2Et chain with H, CO_2Et	188
	OEt	Δ	OCH_2CO_2Et	CO_2Et, EtO cycloheptatriene	110
	$OnPr$	Δ	OCH_2CO_2Et	CO_2Et, $\underline{n}PrO$ cycloheptatriene	188
	OMe, OMe	Δ	OCH_2CO_2Et, OMe	CO_2Et, OMe, OMe cycloheptatriene; CH_2CO_2Et, MeO, OMe	188
	OMe, OMe	Δ	OCH_2CO_2Et, OMe	MeO–CO_2Et, OMe cycloheptatriene	188
	MeO–⬡–OMe	Δ	OCH_2CO_2Et, OMe		188
	OMe (naphthalene)	Δ	OCH_2CO_2Et (naphthalene) 2%	$C_{13}H_{12}O_3$ (unidentified, obtained after saponification)	188

SUBSTRATE CLASS	SUBSTRATE	METHOD	XCH_2CO_2Et PRODUCT	OTHER PRODUCTS	REF.
Simple Alkyl Halide	**tert**-BuBr	Cu-SO$_4$	$BrCH_2CO_2Et$ 7.5%	(H, CO$_2$Et / CO$_2$Et, H) 20%	117
	tert-BuBr	hr	$BrCH_2CO_2Et$ 35.5%	$CH_3C{=}CH_2$ | CH_3	137
	tert-BuCl	hr	$ClCH_2CO_2Et$ 30%	**tert**-BuCHCO$_2$Et | Cl 7.5%	137
	EtBr	hr	$BrCH_2CO_2Et$ 93%	$CH_2{=}CH_2$ $CH_3CH_2CHCO_2Et$ | Br	137
Allylic Alkyl Halide	$CH_2{=}C{-}CH_2Cl$ | Cl	Cu-SO$_4$	$ClCH_2CO_2Et$ 2%	(cyclopropane: Cl, CH$_2$Cl, CO$_2$Et) 17.5% cis 8.5% trans ; $CH_2{=}CCH_2CHCO_2Et$ | | Cl Cl ; (H, CO$_2$Et / CO$_2$Et, H) 8%	60
	$CH_2{=}CH{-}CH_2Cl$	Cu-Cl$_2$	$ClCH_2CO_2Et$ 8%	(cyclopropane: CH$_2$Cl, CO$_2$Et) 4.4% trans ; $CH_2{=}CHCH_2CHCO_2Et$ | Cl 6% ; (H, CO$_2$Et / CO$_2$Et, H) 35%	42
	$CH_2{=}CH{-}CHCl$ | CH$_3$	Cu	$ClCH_2CO_2Et$ 15%	$CH_3CH{=}CHCH_2CHCO_2Et$ | Cl 40% ; CH$_3$ | $CH_2{=}CHCHCHCO_2Et$ | Cl 10%	113
	$CH_3CH{=}CHCH_2Cl$ **trans**	Cu	$ClCH_2CO_2Et$ 19%	$CH_3CH{=}CHCH_2CHCO_2Et$ | Cl 36% ; $CH_2{=}CHCHCHCO_2Et$ | | CH$_3$ Cl 25%	113
	$CH_2{=}CHCH_2Br$	Cu	$BrCH_2CO_2Et$	$CH_2{=}CHCH_2CHCO_2Et$ | Br 68% pure 83% crude	35 42

SUBSTRATE CLASS	SUBSTRATE	METHOD	XCH$_2$CO$_2$Et PRODUCT	OTHER PRODUCTS	REF.
	CH$_2$=CHCH$_2$-I	Cu	ICH$_2$CO$_2$Et 7.5%	CH$_2$=CHCH$_2$CHCO$_2$Et I 47%———70% pure crude	117
Benzylic Halide		Cu-SO$_4$	BrCH$_2$CO$_2$Et 17.5%	32%	189
		Cu-SO$_4$	BrCH$_2$CO$_2$Et 30.5% 40.5%	31% 34%	189 189
		Cu-SO$_4$	BrCH$_2$CO$_2$Et 9.5%	6.5%	125
		Cu-SO$_4$	BrCH$_2$CO$_2$Et	14% 11%	125
Polyhalo Alkane	HCCl$_3$	hr	ClCH$_2$CO$_2$Me 42.5% 34%	ClCHCHCO$_2$Me Cl Cl 10% 17%	114 121

with $CH_3O-\underline{n}C_7H_{15}$ both $CH_3OCH_2CO_2Et$, 16%, and $\underline{n}C_7H_{15}OCH_2CO_2Et$, 27%, are

formed. Surprisingly, elimination of the $\underline{n}$-heptyl group (where β-elimina-

tion is possible) is $\underline{not}$ favored over elimination of the methyl group

(where β-elimination is impossible).[188]

Dyakonov and co-workers in their extensive study of carbethoxycar-

benoid reactions attributed XCH_2CO_2Et formation in some cases to HX elimi-

nation from initially formed C-X insertion product.[117,189] Also some sub-

strates, particularly benzylic halides, were postulated to react via proposed

radical chains that rationalized XCH_2CO_2Et formation as well as other

observed products.[125]

Some other carbenes also have the ability to seize HX from a suitable

substrate. Thus, thermally generated $:CCl_2$ reacts with triethylamine[191] to

form diethyldichloromethylamine, 15%, and with di-$\underline{tert}$-butyl disulfide[192]

yielding 80% $\underline{tert}$-butyldichloromethyl disulfide. Ylid intermediates were

proposed.
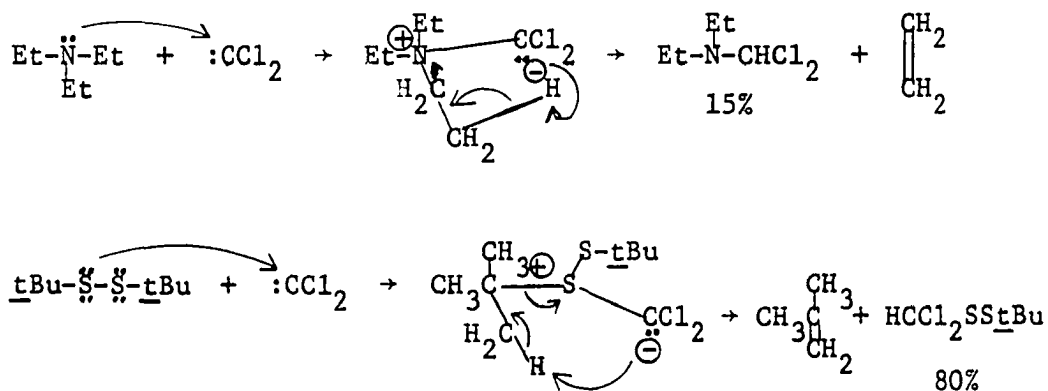
Even photolytically generated methylene eliminates with simple

ethers such as Et_2O and $\underline{n}Bu_2O$.[186,187] Franzen felt that a concerted

cyclic pathway was involved though not via prior ylid formation.[186]

$$EtÖ \!-\! CH_2 \longrightarrow Et\!-\!O\!-\!CH_3 + CH_2\!=\!CH_2$$
$$\begin{array}{c} CH_2\!:\curvearrowright H \end{array} \quad CH_2$$
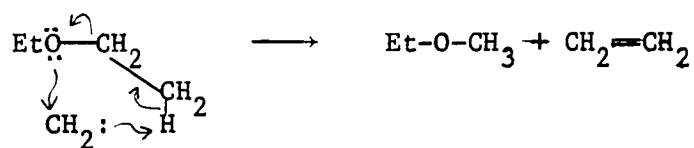
Our goal was simply to gain insight, particularly mechanistic, into the reactions (HX elimination and insertion) of photolytically gen- erated carbethoxycarbene with monohalo compounds. For this purpose the following 21 substrates were eventually involved in the study:

CH_3CH_2Br

CD_3CH_2Br

CH_3CH_2Cl

CH_3CH_2I

$CH_3CHBr \atop CH_3$

$CH_3CHCl \atop CH_3$

$CH_3CHI \atop CH_3$

$CH_3CH_2CHCH_3 \atop Br$

$CH_3CH_2CHCH_3 \atop Cl$

$CH_3CH_2CHCH_3 \atop I$

$CH_3C \!-\! Br \atop CH_3$ (with CH_3 above)

$CH_3C \!-\! Cl \atop CH_3$ (with CH_3 above)

$CH_3C \!-\! I \atop CH_3$ (with CH_3 above)

CH_3Br

$\langle \bigcirc \rangle \!-\! CH_2Cl$

$CH_3C \!-\! CH_2Br \atop CH_3$ (with CH_3 above)

$\langle \bigcirc \rangle \!-\! I$

$CH_3CH_2CHCO_2Et \atop Br$

$nC_6H_{13}F$

(bicyclic structure with Br and D labels)

(bicyclooctane structure with D and Br labels)

$:CH_2CO_2Et \longrightarrow$
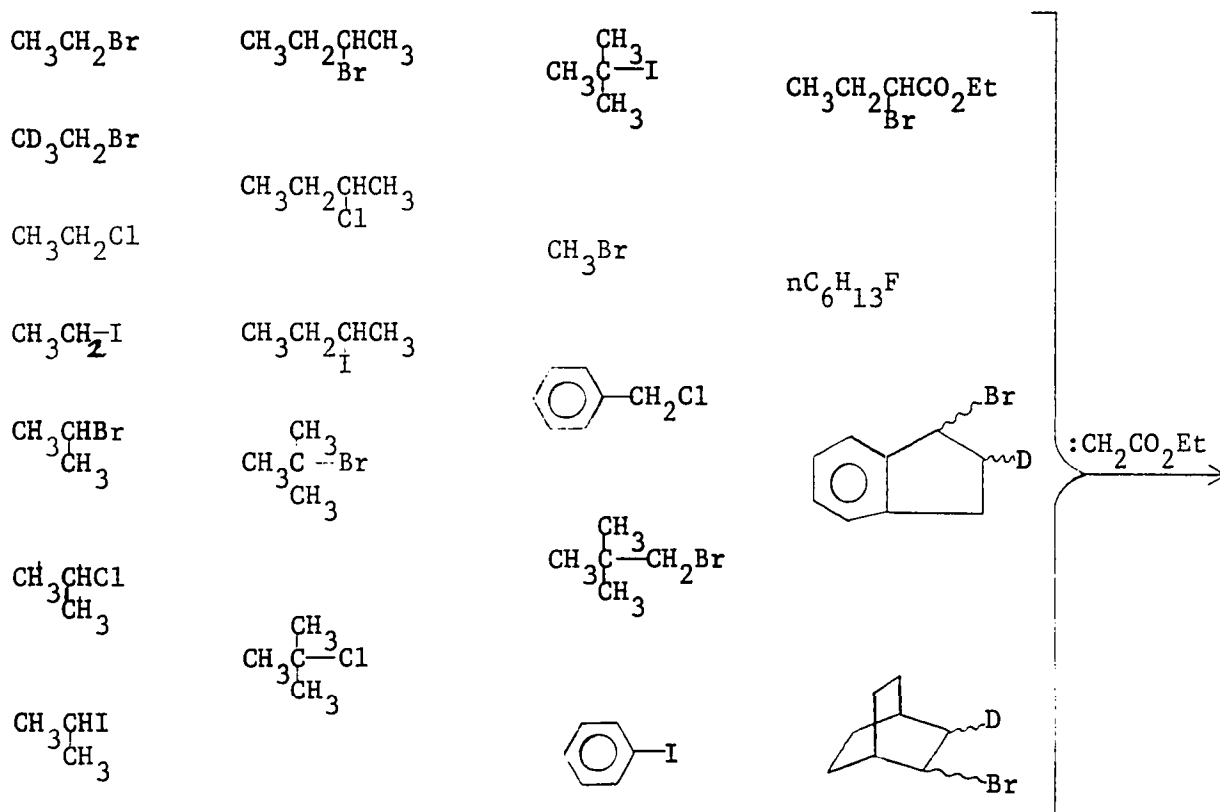
RESULTS AND DISCUSSION

This study was initiated with the aim of delineating the mechanism of :CHCO$_2$Et insertion into C-Halogen bonds. Specifically, C-X insertion involving an optically active substrate was expected to yield valuable mechanistic information. Thus, optically inactive product would strongly implicate a step-wise process involving an intermediate incapable of sustaining optical activity such as a carbonium ion, radical, or carbanion. On the other hand, optically active product would suggest a concerted process involving either retention or inversion at the asymmetric center. Optically active 2-bromobutane was chosen as the substrate for this study because of the ease with which the C-Br insertion product could be converted into a compound of known configurational relationship. Efforts in this direction were soon jeopardized when it became apparent that liquid phase photolysis of ethyl diazoacetate in 2-bromobutane yielded only a trace (i.e., < 5%) of the desired product.

The preferred reaction path involved formation of elimination pro-
ducts; olefin and ethyl bromoacetate. Franzen actually first reported this
type of reaction in 1959.[137] Since other literature information was lack-
ing, it was decided to investigate other simple alkyl halides to ascertain
if, in general, elimination was preferred over insertion for monohalo
alkanes. Thus, ethyl chloride, ethyl bromide, ethyl iodide, isopropyl
chloride, isopropyl bromide, isopropyl iodide, sec-butyl chloride, sec-
butyl bromide, sec-butyl iodide, t-butyl chloride, t-butyl bromide, and
t-butyl iodide were examined; all of which afforded elimination products
to the extent of almost complete exclusion of insertion products.

In view of the cursory nature of Franzen's work and encouraged by
preliminary studies, we undertook a detailed mechanistic investigation
of the photochemically induced reaction of ethyl diazoacetate with simple
alkyl halides.

The results of this study are presented and discussed under the
major areas of concentration: (a) UNIMOLECULAR LOSS OF HBr FROM SUB-
STRATE; (b) C-Br INSERTION PRODUCT AS AN INTERMEDIATE; (c) α OR β ELIMINA-
TION; (d) SINGLET OR TRIPLET; (e) CONCERTED OR STEP-WISE; (f) INFLUENCE
OF PARAMETERS; and (b) CIS OR TRANS ELIMINATION.

UNIMOLECULAR LOSS OF HBr FROM SUBSTRATE:

Consideration was given to the possibility of unimolecular loss
of HBr from electronically excited ethyl bromide.

$$(CH_3-CH_2-Br)^* \longrightarrow CH_2=CH_2 + HBr$$
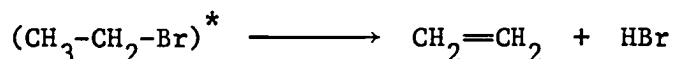
Subsequent fast reaction of the HBr with ethyl diazoacetate would lead
to ethyl bromoacetate.

$$N_2CHCO_2Et + HBr \longrightarrow BrCH_2CO_2Et + N_2$$
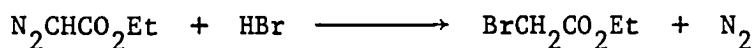
Ethyl bromide absorbs at 2030 A^o (E_{max} = 264)[142] but our reaction em-
ployed a Pyrex filter which cut out light below 3000 A^o. Direct light
absorption by ethyl bromide then should theoretically be almost non-
existent (molar extinction coefficient < 1 above 2600 A^o[142]). Nevertheless,
we photolyzed pure ethyl bromide under our standard reaction conditions
(10°, Pyrex filter, 22 hr, Hanovia 200 watt medium pressure lamp). No
gas evolved; the photolyzed solution was not acidic to moist litmus;
and vpc analysis indicated only the presence of ethyl bromide. As ex-
pected, therefore, direct light absorption by ethyl bromide and subsequent
loss of HBr did not occur.

The possibility remained, however, that in the photolysis of
ethyl diazoacetate in ethyl bromide solution, some species in solution
(ethyl diazoacetate, one of the reaction products, or an impurity) might
be capable of photosensitizing the reaction.

$$CH_3-CH_2-Br \xrightarrow{\text{photosensitizer}} (CH_3-CH_2-Br)^* \longrightarrow CH_2=CH_2 + HBr$$
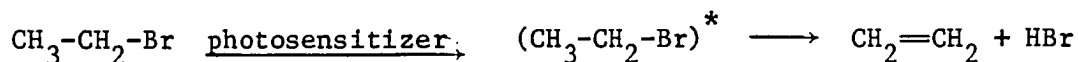
This possibility was suggested to us by Dr. Walter Lwowski[143] and

Dr. H. D. Roth.[144] The photosensitizing agent, after absorbing the

light, would transmit its excitation energy to ethyl bromide. Via

this mechanism, ethyl bromide, after being excited by this indirect

route, would subsequently decompose unimolecularly to form HBr and

ethylene.

We employed the well known sensitizer, benzophenone,[145] to

ascertain if it would induce HBr loss from ethyl bromide. Thus,

a 50 ml, .55 molar solution of benzophenone in ethyl bromide was

photolyzed under our standard reaction conditions (10°, Pyrex filter,

22 hr, Hanovia 200 watt medium pressure lamp). No gas evolved and the

photolyzed solution was not acidic to moist litmus, indicating the

failure of benzophenone to induce this hypothetical reaction. Since

electronically excited ethyl bromide is expected to be a high energy

singlet,[146] a fairer test would involve use of a high energy singlet

sensitizer, rather than the low energy triplet benzophenone. Unfor-

tunately, there are no suitable singlet sensitizing agents available

due to the facile singlet to triplet crossover.[147]

The inertness of pure ethyl bromide to our standard reaction

conditions; the failure of the chosen sensitizer, benzophenone, to

induce loss of HBr from ethyl bromide; and the theoretical implica-

tions involved in forming electronically excited ethyl bromide;

suggest that unimolecular loss of HBr does not occur in our photo-

lysis of ethyl diazoacetate in alkyl halides.

C-Br INSERTION PRODUCT AS AN INTERMEDIATE:

Carbethoxycarbene is known to insert readily into the C-X bond of polyhalo compounds.[114,121] It is somewhat surprising, therefore, that simple monohalo compounds failed to form C-X insertion products (except for very minute amounts, i.e., less than 5%).

One possible explanation to account for this might involve the formation of the C-X insertion product as a transient intermediate leading to the observed products, olefin plus ethyl bromoacetate.

$$R\text{-}X \ + \ :CHCO_2Et \longrightarrow R\text{-}\underset{X}{C}HCO_2Et \longrightarrow olefin \ + \ XCH_2CO_2Et$$
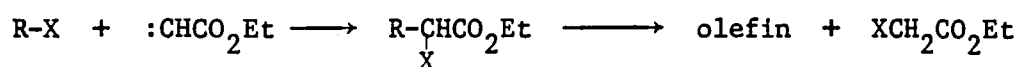
The decomposition of the intermediate may be depicted as a Norrish Type II photoelimination, as illustrated below with ethyl α-bromobutyrate (the product which would result from insertion of carbethoxycarbene into the C-Br bond of ethyl bromide).

$$\longrightarrow \ CH_2\!\!=\!\!CH_2 \ + \ BrCH_2CO_2Et$$
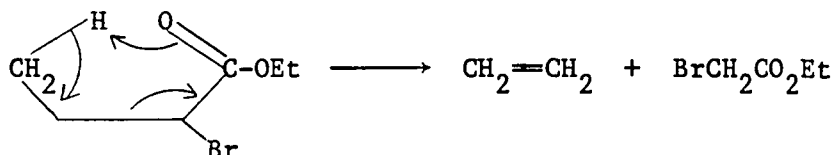
Such photoeliminations are common in many carbonyl compounds.[148]

Ethyl α-bromobutyrate absorbs at 2100 A^o (e_{max} = ca. 50) but our reaction employed a Pyrex filter which cut out light below 3000 A^o. Direct light absorption by ethyl α-bromobutyrate then should theoretically be almost nonexistent (molar extinction coefficient < 1 above 2600 A^o[142,149]). Nevertheless, a 50 ml, .27 molar solution of ethyl α-bromobutyrate in ethyl bromide was photolyzed under our standard reaction conditions (10°, Pyrex filter, 22 hr, Hanovia 200 watt medium pressure lamp). No gas was evolved

and vpc analysis revealed no ethyl bromoacetate. Direct light absorption by ethyl α-bromobutyrate and subsequent decomposition, therefore, did not occur.

The possibility remained, however, that in the photolysis of ethyl diazoacetate in ethyl bromide solution, some species in solution (ethyl diazoacetate, one of the reaction products, or an impurity) might be capable of photosensitizing the reaction of the hypothetical ethyl α-bromobutyrate intermediate.
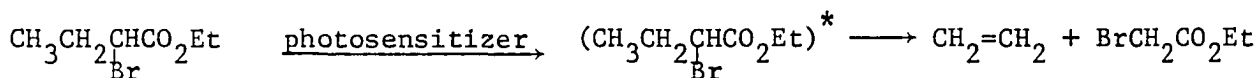
$$CH_3CH_2\underset{Br}{CHCO_2}Et \quad \underrightarrow{\text{photosensitizer}} \quad (CH_3CH_2\underset{Br}{CHCO_2}Et)^* \longrightarrow CH_2=CH_2 + BrCH_2CO_2Et$$

The photosensitizing agent, after absorbing the light, would transmit its excitation energy to ethyl α-bromobutyrate. Via this mechanism, ethyl α-bromobutyrate, after being excited by this indirect route would decompose unimolecularly to form ethylene and ethyl bromoacetate. Dr. Paul de Mayo[150] suggested an indirect experiment to test for this possibility.

Thus, a 50 ml, .80 molar solution of ethyl α-bromobutyrate in benzene was photolyzed employing the usual conditions ($10°$, 22 hr, Hanovia 200 watt medium pressure lamp) except the Pyrex filter was omitted. Under these conditions essentially all the energy should be absorbed by benzene[150] which then could theoretically transfer this energy to the ethyl α-bromobutyrate. No gas was evolved and vpc analysis revealed no ethyl bromoacetate, indicating the failure of benzene to induce this hypothetical reaction.

Even so, the possibility remained that in the photolysis of ethyl

diazoacetate in ethyl bromide solution, some species in solution (ethyl diazoacetate, one of the reaction products, or an impurity) might be serving as the sensitizing agent. Dr. John G. Burr,[146] suggested a direct test for this possibility.

Thus, a 50 ml, .80 molar solution of ethyl diazoacetate in ethyl bromide was prepared. To this solution was added 2.0 g of ethyl α-bromobutyrate. After photolysis under the usual conditions (10°, Pyrex filter, 22 hr, Hanovia 200 watt medium pressure lamp) vpc analysis revealed the presence of 15.0 mm, 37.5% of ethyl bromoacetate. This yield of ethyl bromoacetate is near that normally (i.e., with no ethyl α-bromobutyrate added) obtained, ca. 40%. Furthermore, the added ethyl α-bromobutyrate was all still present in the reaction solution. Thus, no ethyl α-bromobutyrate was converted to ethyl bromoacetate, indicating that there was no species in solution serving as sensitizer.

This result also rules out the possibility of any contribution from the hypothetical reaction,

$$CH_3CH_2\underset{Br}{CH}CO_2Et \ + \ N_2CHCO_2Et \longrightarrow CH_3CH{=}CHCO_2Et \ + \ BrCH_2CO_2Et$$
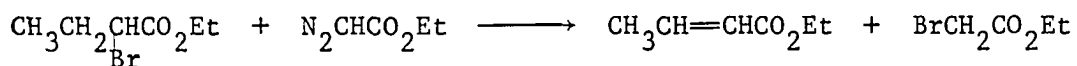
an analogy of which has been proposed[117,189] to account for XCH_2CO_2Et among the products formed in the reaction of carbethoxycarbene with some monohalo substrates.

Despite these findings it was still conceivable that initially formed vibrationally (not electronically) excited C-Br insertion product, ethyl α-bromobutyrate, could be rapidly decomposing to observed products. Similar phenomena have been observed in gas phase reactions.[17,151] No

direct experimental test was made that would exclude this possible

pathway. However, such an occurence in solution is rare since the

rate of collisional deactivation equals approximately 10^{12} sec^{-1}.[17]

The inertness of ethyl α-bromobutyrate in ethyl bromide solution to our standard reaction conditions; the failure of the chosen benzene sensitizer to induce ethyl α-bromobutyrate to undergo Norrish Type II photoelimination; and the failure under our standard reaction conditions of ethyl α-bromobutyrate added to an ethyl bromide solution of ethyl diazoacetate to increase the total amount of ethyl bromoacetate produced; rule out any mechanism involving transient, electronically excited ethyl α-bromobutyrate as an intermediate. Furthermore, theoretical implications concerning the fate of any initially formed, vibrationally excited ethyl α-bromobutyrate, suggest the high probability that it is not an intermediate leading to our observed products.

α OR β ELIMINATION:

A substrate, CD_3CH_2Br, was selected in order to determine whether the carbene induced elimination of hydrogen halide was an α or β process. This material was prepared in 65.7% overall yield, starting with tetra-deuteroacetic acid.

$$CD_3CO_2D \ + \ LiAlH_4 \ \longrightarrow \ \underset{70\%}{CD_3CH_2OH} \ \xrightarrow{\text{48\% HBr}} \ \underset{93.9\%}{CD_3CH_2Br}$$
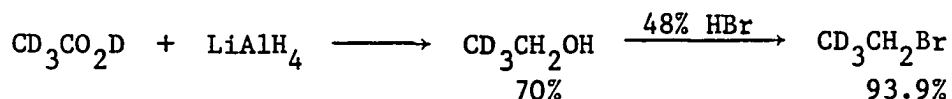
There are numerous literature reports of the formation of small amounts of ethyl haloacetate from alkyl halides in reactions with ethyl diazoacetate.[35,42,113,117,137] Some of these have no available β-hydrogen and, therefore, may conceivably involve direct α-HX elimination.[60,121,125,189] Carbethoxycarbene reaction with CD_3CH_2-Br via an α-elimination may be depicted as shown below.

$$CD_3CH_2Br \ + \ :CHCO_2Et \ \longrightarrow \ BrCH_2CO_2Et \ + \ \underset{H}{\overset{D}{CD_2\text{-}C:}} \ \xrightarrow[\sim \ D:]{\text{1,2 shift}} \ \overset{D}{CD_2\text{=}CH}$$
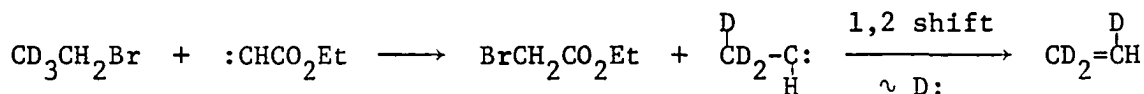
This mechanism might _a priori_ be considered unlikely since the production of CD_3CH: would be expected to be a highly endothermic process. The deuterium label allowed an unequivocal determination to be made. Thus, d_3-ethylene is a predicted α-elimination product. The evolved ethylene was, therefore, collected in a gas bulb. Subsequent mass spectrometric analysis revealed no trace of d_3-ethylene. Furthermore, mass spectrometric analysis of the other elimination product revealed no d_0-ethyl bromoacetate (as would be required if an α-elimination were operative).

Actual composition of the products was d_2-ethylene and d_1-ethyl bromo-acetate indicating the actual mechanism to involve a β-elimination pathway.

Two substrates were examined to determine if α-elimination could occur where no β-protons were available. Reaction of carbethoxycarbene with benzyl chloride resulted in no ethyl chloroacetate. Similarly, reaction with neopentyl bromide produced no ethyl bromoacetate.
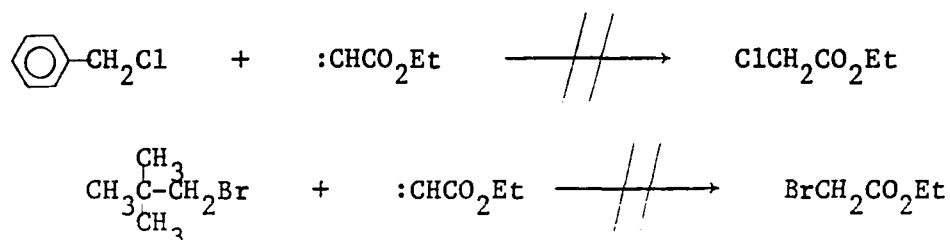
$$\langle\bigcirc\rangle\text{-CH}_2\text{Cl} \quad + \quad :\text{CHCO}_2\text{Et} \quad \xrightarrow{\quad//\quad} \quad \text{ClCH}_2\text{CO}_2\text{Et}$$

$$\text{CH}_3\underset{\underset{\text{CH}_3}{|}}{\overset{\overset{\text{CH}_3}{|}}{\text{C}}}\text{-CH}_2\text{Br} \quad + \quad :\text{CHCO}_2\text{Et} \quad \xrightarrow{\quad//\quad} \quad \text{BrCH}_2\text{CO}_2\text{Et}$$

The formation of d_2-ethylene (no d_3-ethylene) and d_1-ethyl bromo-acetate (no d_o-ethyl bromoacetate) in the reaction of carbethoxycarbene with $\text{CD}_3\text{CH}_2\text{Br}$ rules out even the partial participation of an α-elimination pathway. Thus, preference for a β-elimination mode has been firmly established for systems with available β-protons. The failure of the two substrates without β-protons to yield elimination products suggests that in general not only is α-elimination less favorable than β-elimination but in fact altogether impossible for such monohalo substrates.

SINGLET OR TRIPLET:

Carbethoxycarbene is theoretically capable of existing in either the singlet (spins paired) or triplet (spins unpaired) form.[24] Available evidence indicates that liquid phase reactions of carbethoxycarbene (gas phase studies have not been made[19]) involve the singlet form.[22,28,29,96,152] Thus, it adds stereospecifically _cis_ to olefins.[19,28,29] This strongly suggests that singlet carbethoxycarbene is the reactive species since triplet carbenes have __experimentally__ been found not to add stereospecifically (although triplets could __theoretically__ do so via the interaction of solvent cage effects).[25,153,154]

Photolysis of diazo carbonyl compounds in general (in the absence of sensitizer) seems to result in initial formation of singlet carbene which either reacts with the substrate or decays to the ground state triplet form and subsequently reacts with the substrate.[20,22,24,153,155-158] Some carbenes apparently decay readily to the triplet form and then react.[22,24,153,156,158,159] This is made even more facile by the use of a relatively inert solvent or a heavy atom solvent so that energy transfer via non-reactive collision may occur.[22,24] For example, bis-carbethoxycarbene normally adds stereospecifically to olefin via the singlet.[160] In hexafluorobenzene solvent (almost inert), however, it adds nonstereospecifically via the triplet.[160] Contrariwise, carbethoxycarbene apparently does not decay to the triplet form in hexafluorobenzene.[96]

In general, one may theoretically obtain triplet carbenes from diazo compounds via the use of a photosensitizer such as benzophenone.[161] Benzophenone absorbs strongly at 3130 A$^{\circ}$; whereas, diazo compounds (such as diazomethane, ethyl diazoacetate, and bis-ethyl diazomalonate) have an

absorption minimum in this region.[161] By using filters to block out

light where the diazo compound absorbs strongly, one may selectively

excite benzophenone.[161] This sets in motion the events depicted below.[162]

$$Ph_2CO \xrightarrow{hr} (Ph_2CO)^* \longrightarrow (Ph_2CO)^* \xrightarrow{RN_2} (RN_2)^* \longrightarrow \uparrow.R.\uparrow + N_2$$

                    singlet   triplet   triplet   triplet
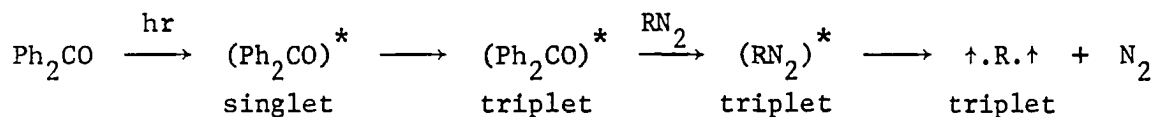
A 50 ml ethyl bromide solution containing 40 mm of ethyl diazo-

acetate and 40 mm of benzophenone was prepared. This solution was photo-

lyzed as usual except that both a Pyrex filter and a chemical filter were

used. The chemical filter consisted of an aqueous solution of nickel

sulfate (.18 molar) and cobalt sulfate (.18 molar). This filter solution

circulated through the immersion well and, thus, served also as coolant

to dissipate heat generated by the lamp. The Pyrex filter blocked out

light below 3000 A° and the chemical filter solution was designed to

eliminate most of the light above 3300 A°.[163-165] The yield of ethyl

bromoacetate was 16.6%; whereas, without added sensitizer the usual yield

was ca. 40%. This implies that under normal conditions (no sensitizer)

that singlet carbethoxycarbene is the reactive species. Possibly, the

photosensitized reaction produces mostly triplet carbene but also some

singlet.[96]

Singlet electrophilic carbenes do not react with oxygen; whereas,

triplets do react.[166,167] Three control experiments were run in order

to ascertain the effect of oxygen on our reaction. A 250 ml, .35 molar

solution of ethyl diazoacetate in ethyl bromide was photolyzed (10°,

Pyrex filter, 48 hr, Hanovia 200 watt medium pressure lamp) and a 37.8%

yield of ethyl bromoacetate obtained. The reaction was repeated

exactly except that the ethyl bromide used was saturated with nitrogen

and nitrogen bubbled through the solution during photolysis; a 37.5%

yield of ethyl bromoacetate was obtained. Finally, the reaction was

repeated exactly except that the ethyl bromide used was saturated with

oxygen and oxygen was bubbled through the solution during photolysis;

a 32.0% yield of ethyl bromoacetate was obtained. The slight decrease

in yield in the latter case indicates that triplet carbethoxycarbene

is present to only a slight extent if at all.

Triplet carbenes react with oxygen to form ketones (or aldehydes,

etc.) and also induce oxidation (to alcohol and ketone) of hydrocarbon

solvents such as cyclohexane.[156] We, therefore, ran an analogous set

of experiments involving .35 molar solutions of ethyl diazoacetate in

cyclohexane (no alkyl halide present). The C-H insertion product, ethyl

cyclohexylacetate, was obtained in yields of 38.3% (no stream of N_2

or O_2), 38.7% (N_2 stream), and 35.5% (O_2 stream). This slight decrease

in yield in the latter case indicates that triplet carbethoxycarbene

is present to only a slight extent if at all.

The general literature concerning the photolysis of ethyl diazo-

acetate and other diazo compounds; the stereospecific addition of carbeth-

oxycarbene to olefins; the dramatic reduction in yield of ethyl bromo-

acetate under the conditions favoring triplet formation; the slight effect

of O_2 on carbethoxycarbene reaction in ethyl bromide; strongly indicate

that singlet :$CHCO_2Et$ is the reactive species involved in the induced

elimination of hydrogen halide from alkyl halides.

CONCERTED OR STEP-WISE:

Consideration was given as to whether the C-H and C-X bonds broke at the same time or in a step-wise fashion. Since the relative reactivities of isopropyl chloride, isopropyl bromide, and isopropyl iodide toward carbethoxycarbene were of interest, an experiment to determine this information was designed. The results obtained were mechanistically much more informative than anticipated.

Ethyl diazoacetate was photolyzed in a solution containing equimolar quantities of isopropyl chloride, bromide, and iodide. Thus, these isopropyl halides competed with one another in reacting with carbethoxycarbene as it was generated. Vpc analysis revealed the following relative product yields.

	millimole %	number of runs
$ClCH_2CO_2Et$	21.4	3
$BrCH_2CO_2Et$	31.5	3
ICH_2CO_2Et	46.9	3

The product distribution is a direct reflection of the rates of the three competing reactions. The relative rates (i.e., relative reactivities) were computed by making k_{Cl} = 1; thus,

				Divide by	Relative Reactivity
$\overset{CH_3}{\underset{}{CH_3CHCl}}$	$\longrightarrow$	$ClCH_2CO_2Et$	21.4%	21.4% $\longrightarrow$	k_{Cl} = 1.0
$\underset{CH_3}{CH_3CHBr}$	$\longrightarrow$	$BrCH_2CO_2Et$	31.5%	21.4% $\longrightarrow$	k_{Br} = 1.47 ± .01
$\underset{CH_3}{CH_3CHI}$	$\longrightarrow$	ICH_2CO_2Et	46.9%	21.4% $\longrightarrow$	k_I = 2.20 ± .17

The relative rates of product formation are a reflection of the bond strengths of the C-I, C-Br, and C-Cl bonds with C-I being most favored and C-Cl least favored. This suggests significant C-X bond stretching in the transition state. The average homolytic bond energies are C-Cl 81 kcal, C-Br 68 kcal, and C-I 51 kcal.[168] A plot of these bond energies vs. relative reactivities is linear (Figure 2).
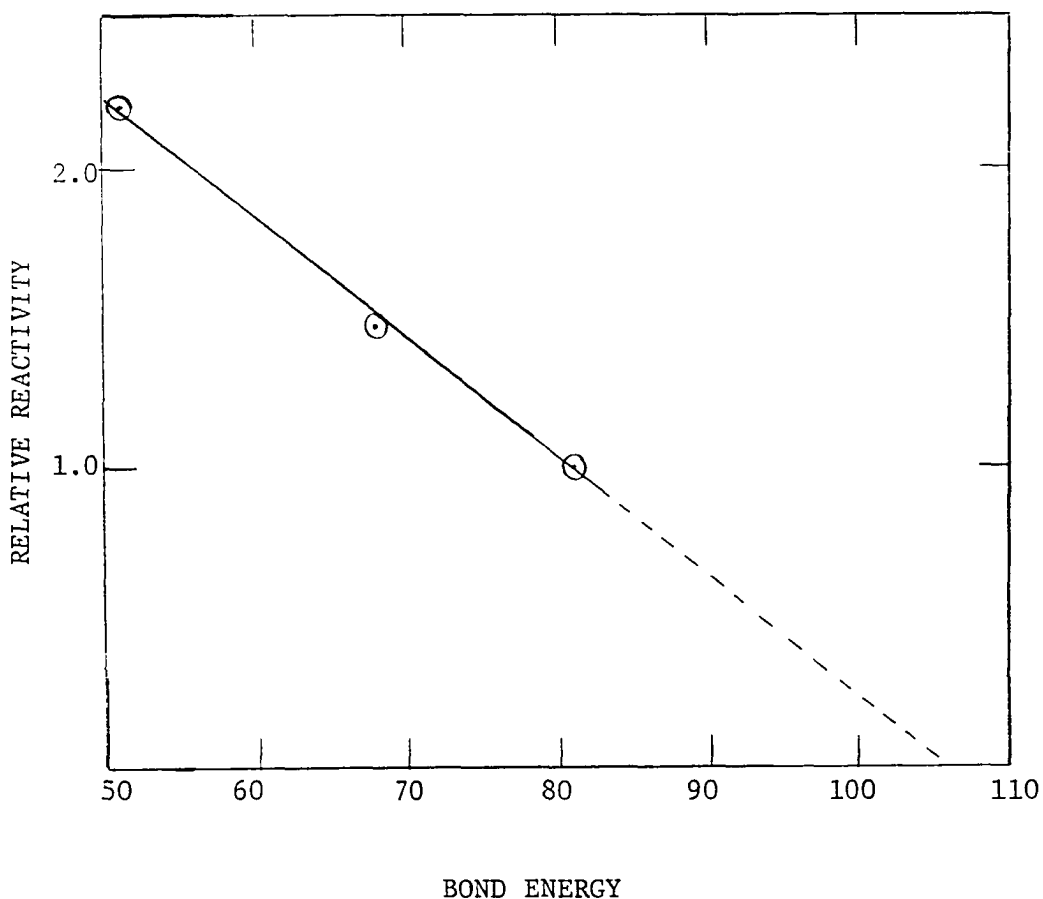
Figure 2. Plot of isopropyl halide reactivity toward carbethoxycarbene vs. C-X average homolytic bond energy.

Note that if the line extrapolated to the X-intercept, the bond energy, 106 kcal, is near that of a C-F bond, 116 kcal.[168] The predicted zero reactivity was checked by reacting 1-fluorohexane with carbethoxy-carbene. None of the HF elimination product, FCH_2CO_2Et, was formed.

To assess the significance of these findings a literature search on alkyl halide solvolysis was made. The relative rates of solvolysis of t-butyl iodide, t-butyl bromide, and t-butyl chloride under identical conditions (80% EtOH, 25°) were found to be 99, 39.4, and 1 respectively.[169]

Relative reactivity

$$CH_3 \underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}-X \quad \xrightarrow[25\%]{80\% \ EtOH} \quad CH_3 \underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}} \oplus$$

X = Cl	X = Br	X = I
1.0	39.4	99
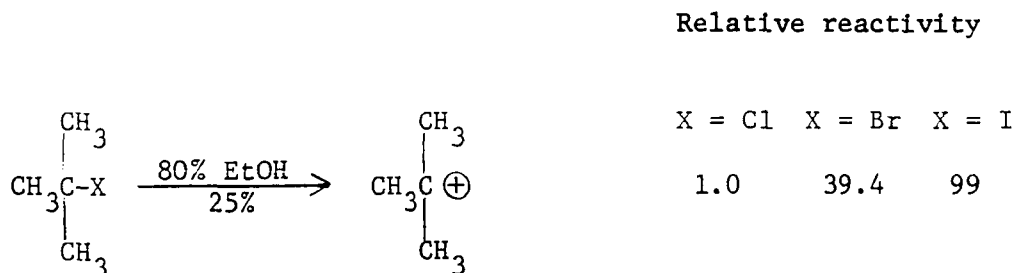
For this series of unimolecular reactions the relative reactivities vary linearly with the average C-X homolytic bond energies (Figure 3).
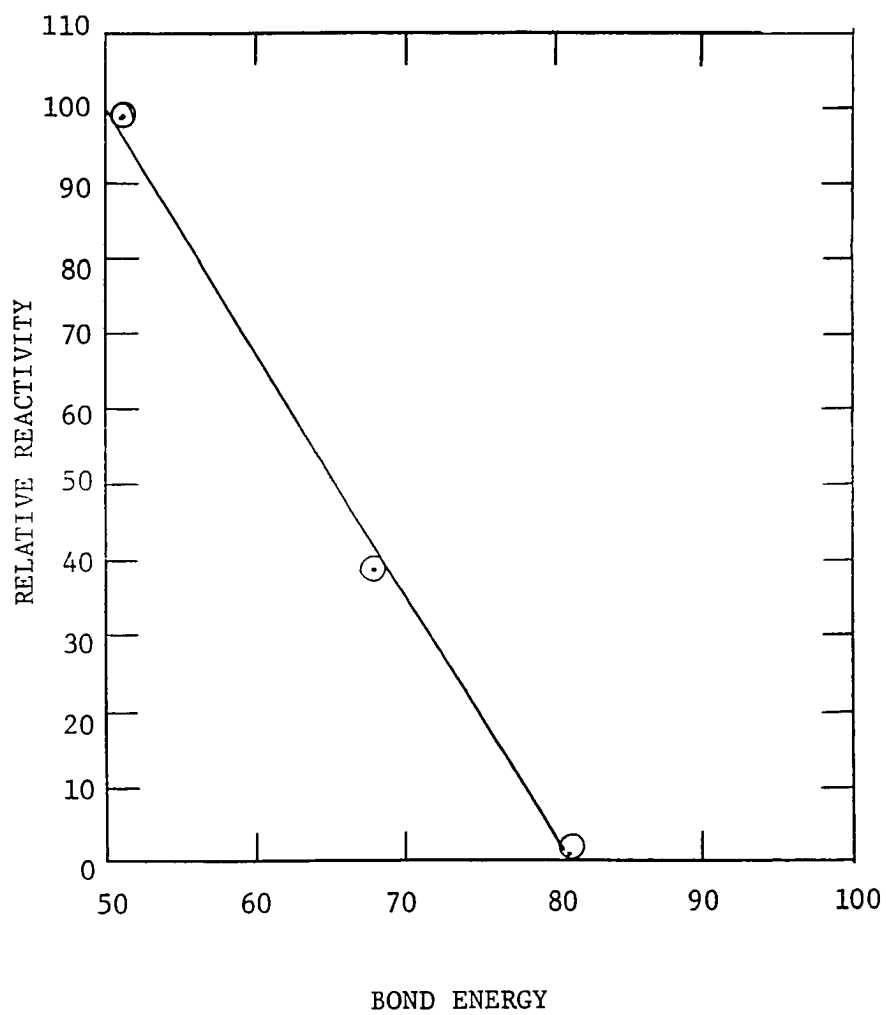
Figure 3. Plot of t-butyl halide solvolysis reactivity (80% EtOH, 25°) vs. C-X average homolytic bond energy.

Furthermore, the relative rates of solvolysis of neopentyl iodide, bromide, and chloride under identical conditions (80% EtOH, 25°) vary linearly with the average C-X __homolytic__ bond energies (Figure 4).[169]

Relative reactivity

CH₃C-X $\xrightarrow{\frac{80\% \text{ EtOH}}{25°}}$ CH₃C ⊕

X = Cl	X = Br	X = I
1.0	42.1	113
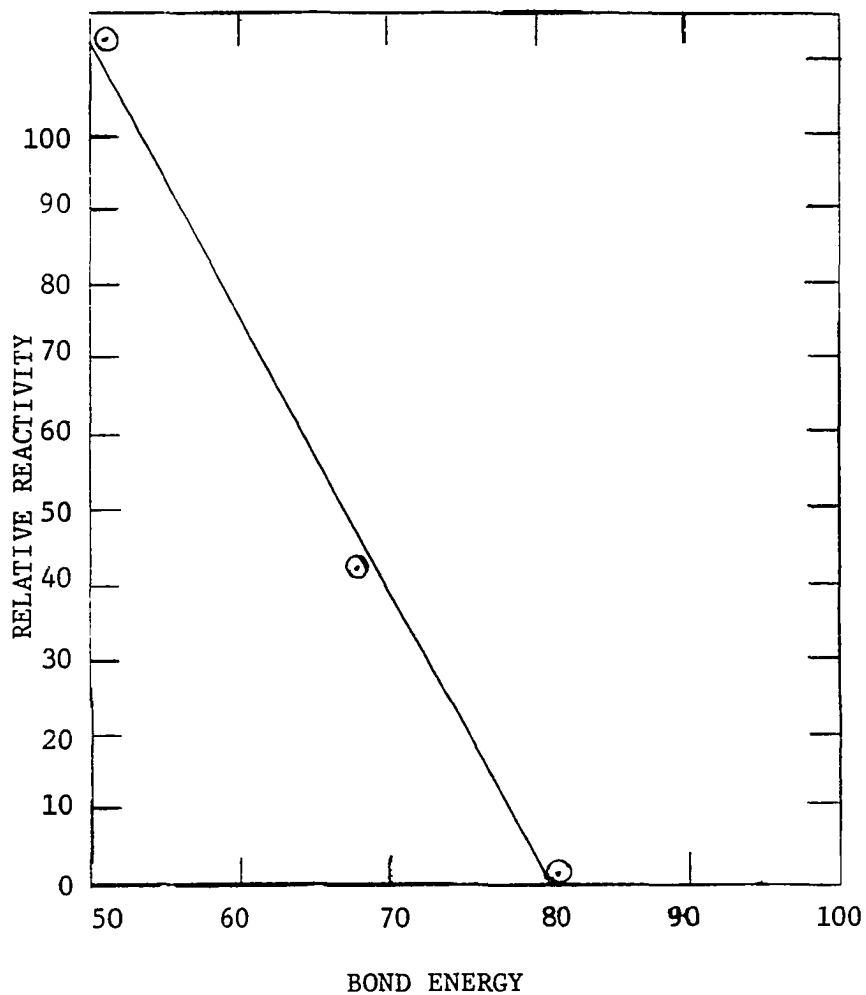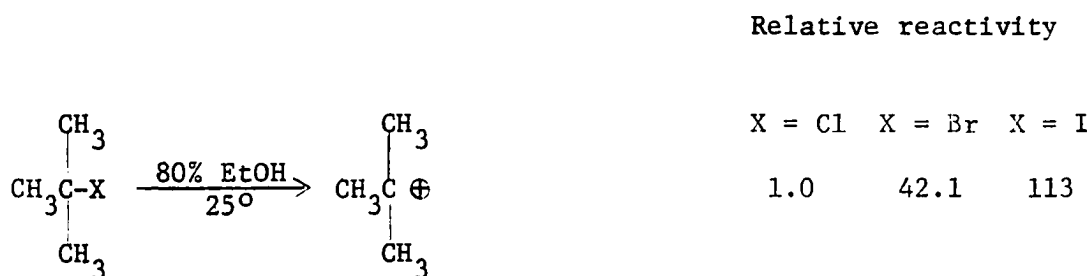
Figure 4. Plot of neopentyl halide solvolysis reactivity (80% EtOH, 25°) vs. C-X average homolytic bond energy.

For the t-butyl halide and neopentyl halide series, of course, the unimolecular C-X bond cleavage is the rate determining step. The relative rates of product formation are a reflection of the bond strengths of the C-I, C-Br, and C-Cl bonds with C-I being the most favored and C-Cl least favored. These C-X bonds suffer heterolytic cleavage and it is, therefore, surprising that linear relationships exist between the relative rates and the average C-X homolytic bond energies. Nevertheless, the fact is that these linear relationships do exist. We must either dismiss as fortuitous the analogy of the linear relationships involving alkyl halide reaction with carbethoxycarbene and those involving alkyl halide solvolyses, or else accept the implication that they are mechanistically related.

Assuming, momentarily, that the carbethoxycarbene reaction with alkyl halides involves carbonium ion like intermediates, an explanation is required (involving some factor other than bond energy) for the small relative reaction rate values; $k_I = 2.2$, $k_{Br} = 1.47$, and $k_{Cl} = 1.0$. These values seem particularly small in view of the C-X bond energy differences and the large values in the solvolyses reactions.

One possible explanation lies in a consideration of the fate and environment of the departing halide ion (the R⊕ may be ignored since it is invariable). In solvolyses the halides exist as free, dissociated $I^\ominus$, $Br^\ominus$, and $Cl^\ominus$. As such they maintain appreciably different aptitudes for existence due to the charge isolation, varying atomic electronegativities, and solvation. This is reflected in the large relative reaction rates.

Consider, however, the hypothetical situation involving carbethoxycarbene and alkyl halide.

$$R-X: \underset{HC=\!\!=\overset{|}{C}-OEt}{\overset{:CH-\overset{O}{\overset{\|}{C}}-OEt}{\Big\langle}} \quad \underset{\text{fast}}{\rightleftharpoons} \quad \underset{R-\overset{\oplus}{X}-CH=\overset{|}{C}-OEt}{\overset{R-\overset{\oplus}{X}-\overset{\ominus}{CH}-\overset{O}{\overset{\|}{C}}-OEt}{}} \quad \underset{\text{slow}}{\longrightarrow} \quad \underset{R^{\oplus} \quad X-\overset{|}{\underset{H}{C}}=C-OEt}{\overset{R^{\oplus} \quad X-\overset{\ominus}{\overset{..}{C}}-\overset{O}{\overset{\|}{C}}-OEt}{}}$$
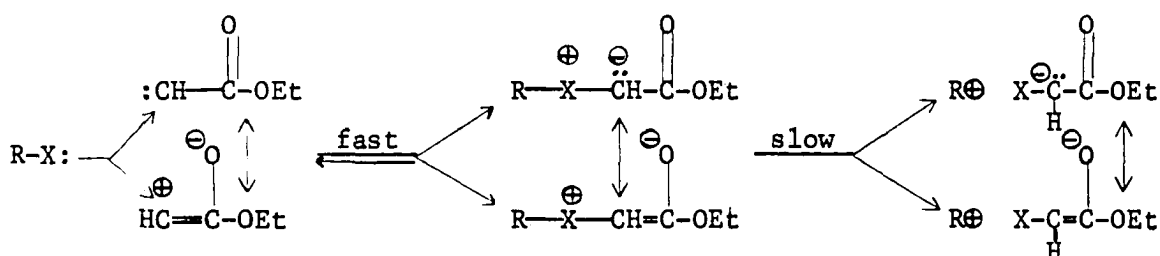
The halogens exist as part of the counteranion. Since the reaction solution is relatively non-polar and the intermediate doesn't undergo skeletal rearrangement (as discussed later), a free dissociated, solvated, carbonium ion and counteranion are not likely. A tight carbonium ion pair intermediate, however, would appear to be energetically favorable due to the appreciable electrostatic stabilization between the positive alkyl and the negative counteranion.[170] The counteranions involved $ClCH=\!\!\overset{\ominus}{\underset{}{C}}\overset{O}{\underset{}{}}OEt$, $BrCH=\!\!\overset{\ominus}{\underset{}{C}}\overset{O}{\underset{}{}}OEt$, and $ICH=\!\!\overset{\ominus}{\underset{}{C}}\overset{O}{\underset{}{}}OEt$ should have only minor stability differences and, therefore, would not maintain appreciably different aptitudes for existence. This is reflected in the small relative reaction rates.

Kinetic data was sought in order to gain more information concerning the C-H and C-X bond cleavages. A 50 ml, .80 molar solution of ethyl diazoacetate in CH_3CH_2Br was photolyzed under standard conditions ($10°$, Pyrex filter, 22 hr, Hanovia 200 watt medium pressure lamp). The evolved gases, N_2 and ethylene, were channeled through a carbon tetrachloride solution of bromine to trap the ethylene. The nitrogen continued on and was collected over water. By following the course of nitrogen evolution the rate of ethyl diazoacetate decomposition was computed. A first order plot was obtained with a rate constant of $k = 4 \times 10^{-3}$ min^{-1} (Figures 5, 6 and 7, Tables 2, 3, and 4).

Next, the course of ethylene formation was followed by collecting

both N_2 and ethylene and then subtracting the previously obtained data for

N_2 evolution. A first order plot was obtained with a rate constant of

ca. 4×10^{-3} min^{-1} (Figure 8, Table 5).

These experiments were repeated using CD_3CH_2Br as substrate.

Again, first order plots with rate constants of k = 4×10^{-3} min^{-1} were

obtained for both ethyl diazoacetate decomposition and ethylene for-

mation (Figures 9, 10, 11, and 12, Tables 6, 7, 8, and 9).

These results suggest that the initial loss of N_2 to produce the

carbene is the overall rate determining step.

$$N_2CHCO_2Et \xrightarrow{slow} N_2 + :CHCO_2Et$$

$$:CHCO_2Et + CH_3CH_2Br \xrightarrow{fast} products$$
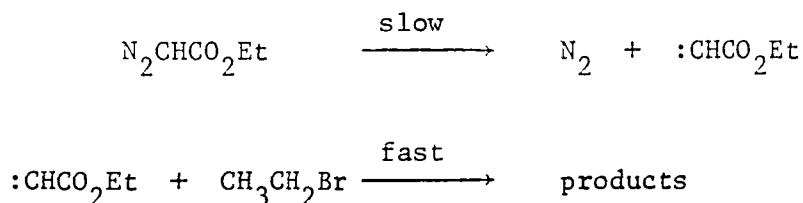
Competition experiments were performed in which mixtures of CH_3CH_2Br

and CD_3CH_2Br were allowed to compete for carbethoxycarbene as it was gen-

erated. This allowed information to be obtained about the isotope effect

in the reaction step which was decisive for the choice between different

isotopic species, i.e.,

$$\begin{matrix} CD_3CH_2Br \\ CH_3CH_2Br \end{matrix} \rightarrow :CHCO_2Et \rightarrow products$$
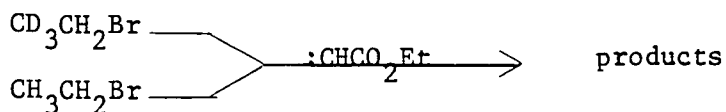
even though this was not the rate determining step for the overall

reaction.[171] Thus, when equal amounts of CH_3CH_2Br and CD_3CH_2Br competed
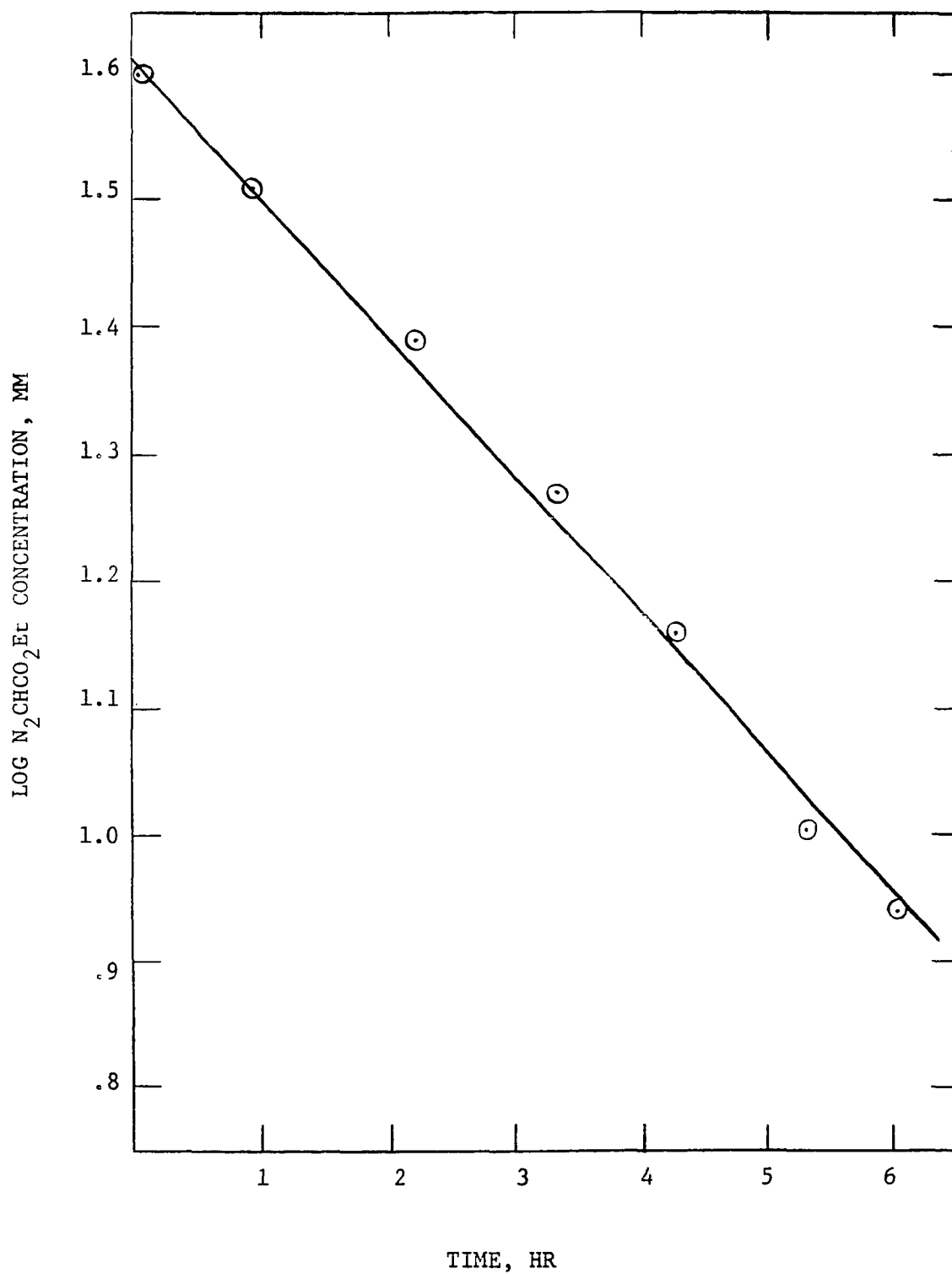
Figure 5. Plot of ethyl diazoacetate decomposition in CH_3CH_2Br vs. time at 10°.
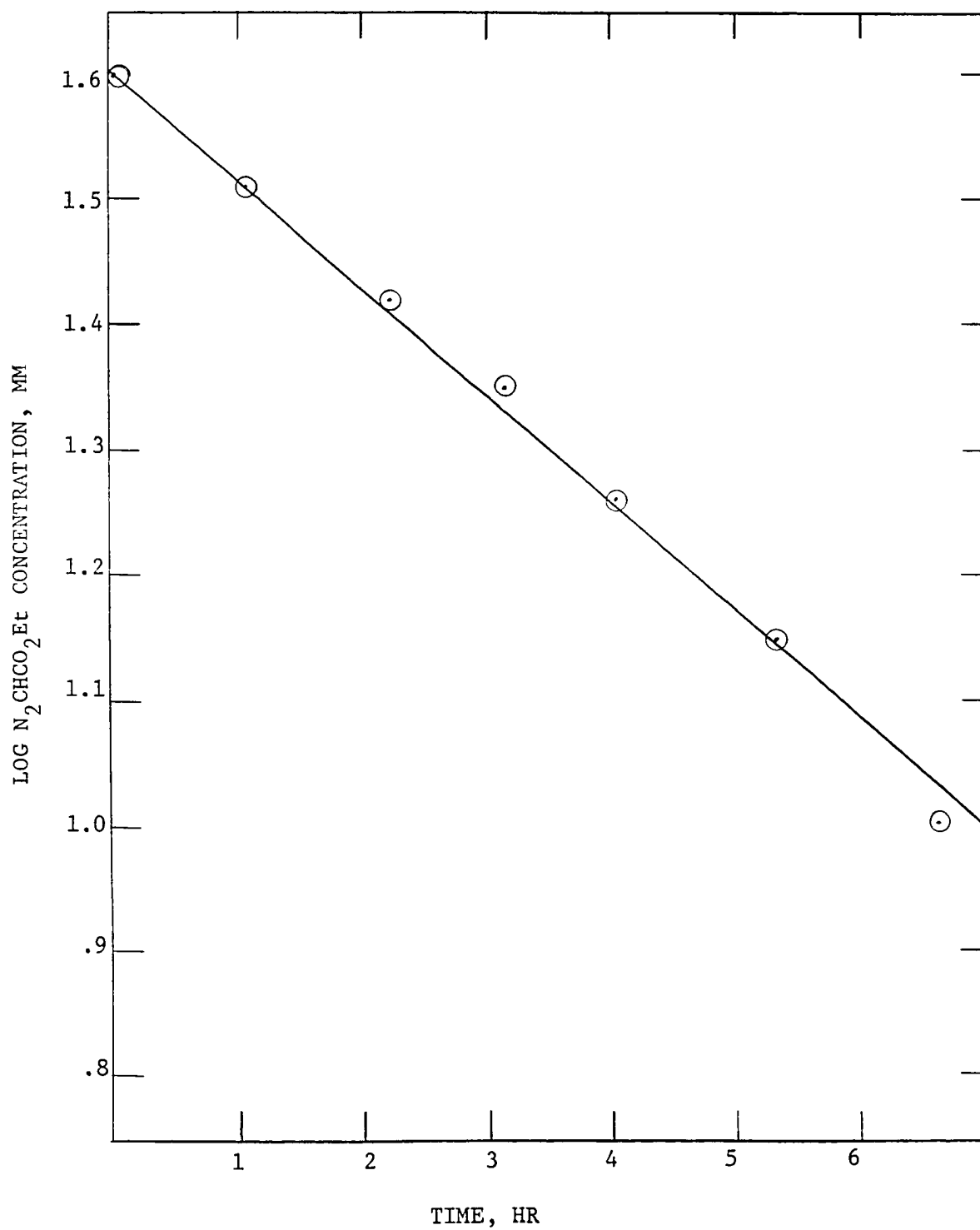
Figure 6. Plot of ethyl diazoacetate decomposition in CH_3CH_2Br vs. time at 10°.
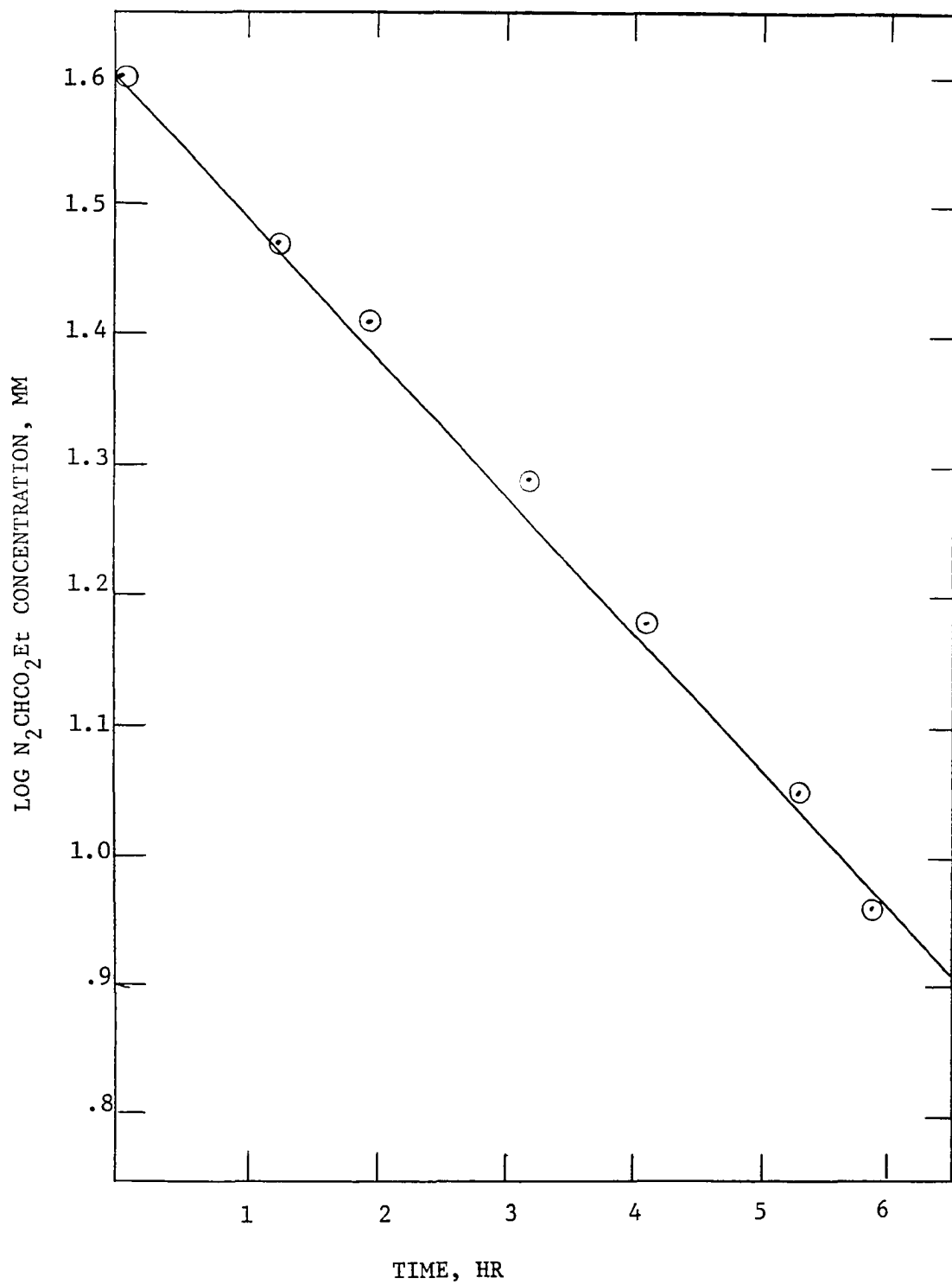
Figure 7. Plot of ethyl diazoacetate decomposition in CH_3CH_2Br vs. time at 10°.
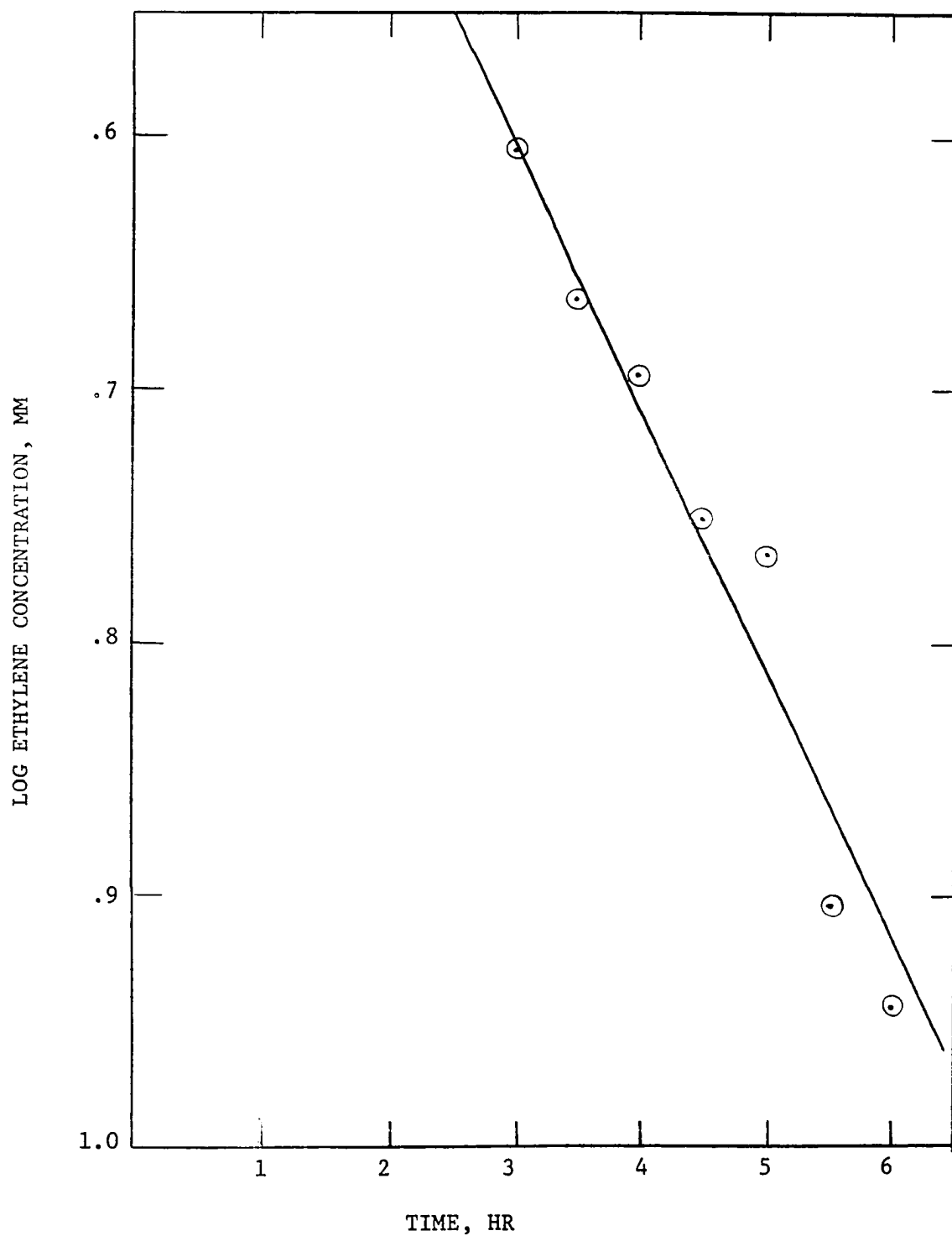
Figure 8. Plot of CH_2=CH_2 formation vs. time during ethyl diazoacetate photolysis in CH_3CH_2Br at 10°.
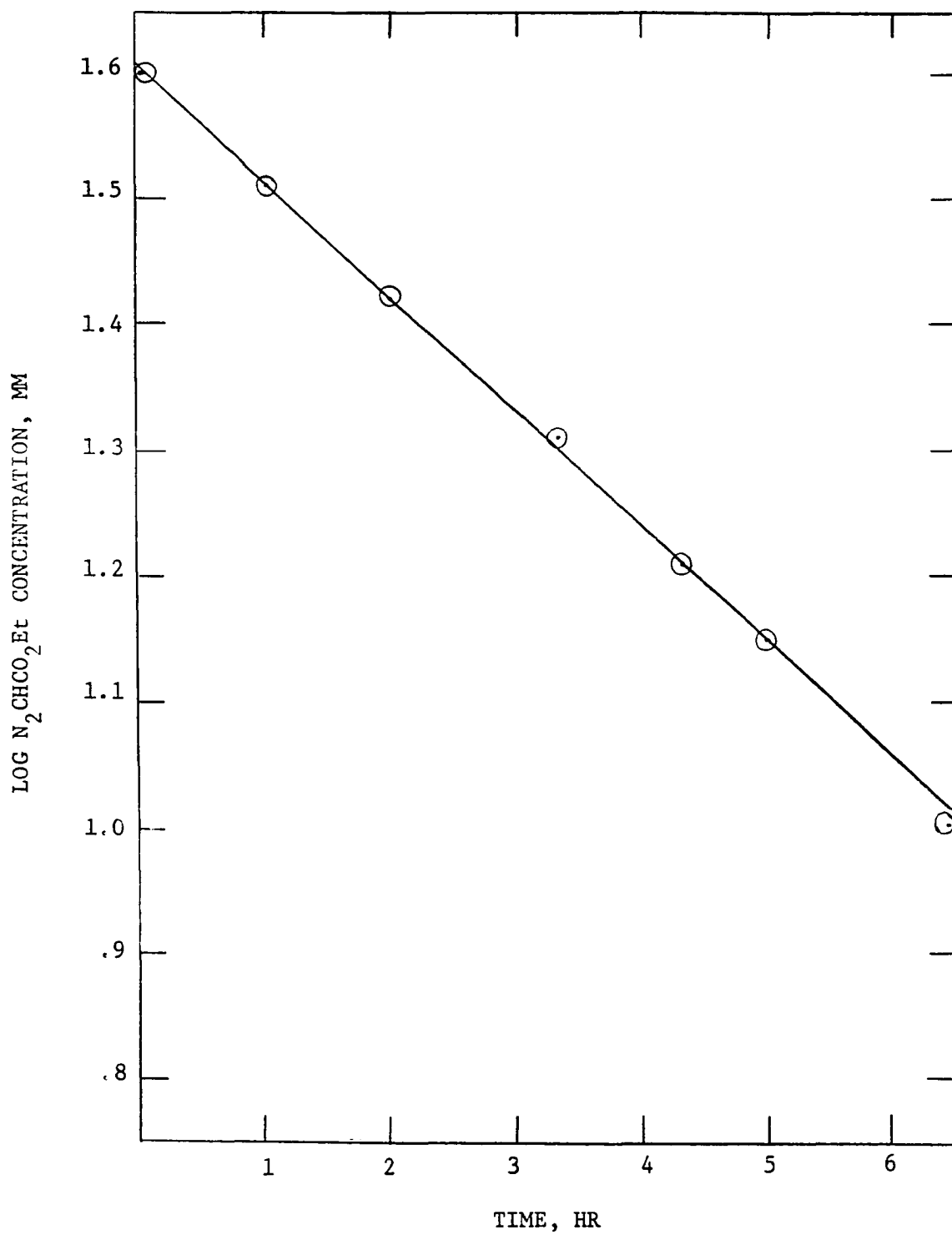
Figure 9. Plot of ethyl diazoacetate decomposition in CD_3CH_2Br vs. time
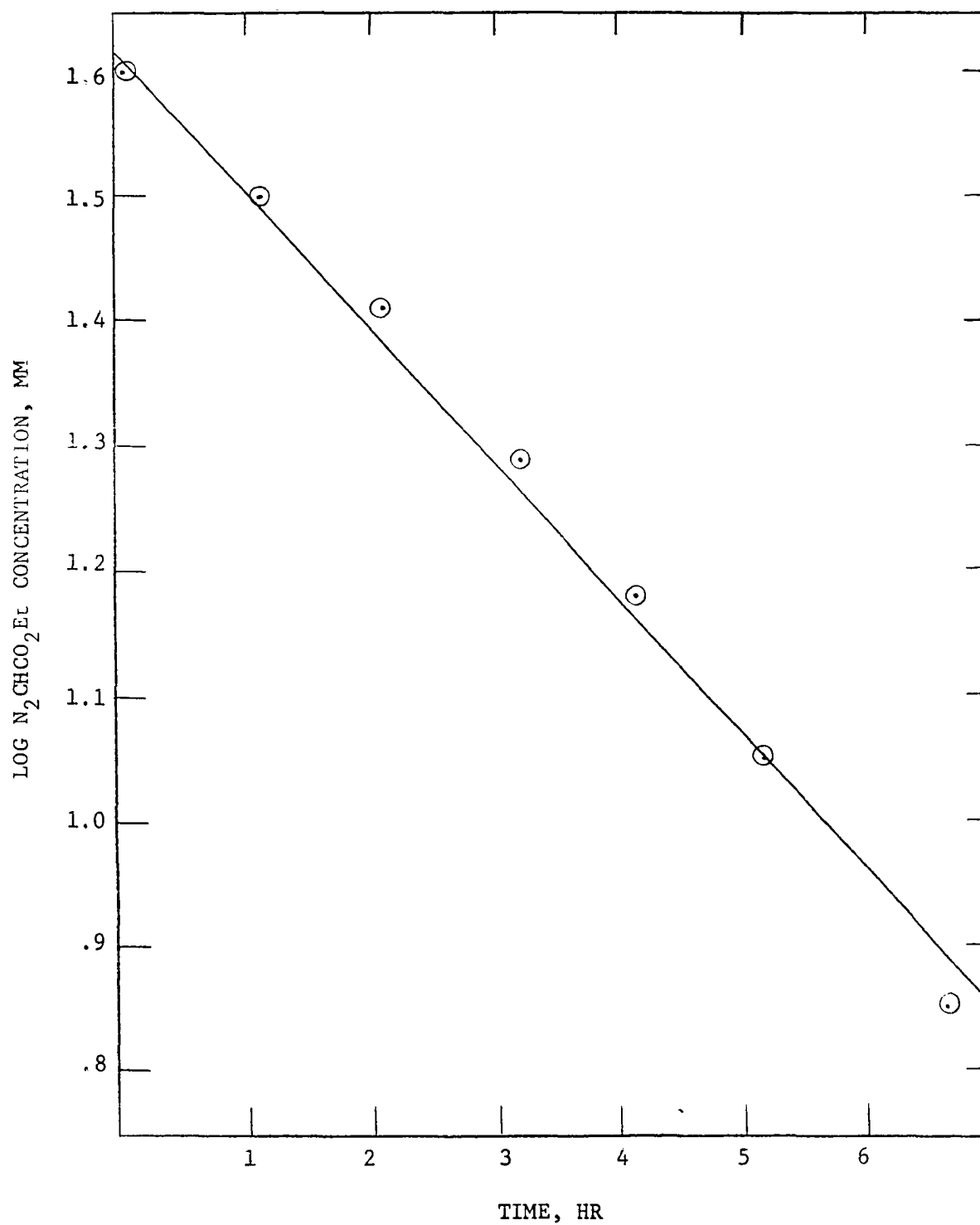
at $10°$.

Figure 10. Plot of ethyl diazoacetate decomposition in CD_3CH_2Br vs. time at 10°.
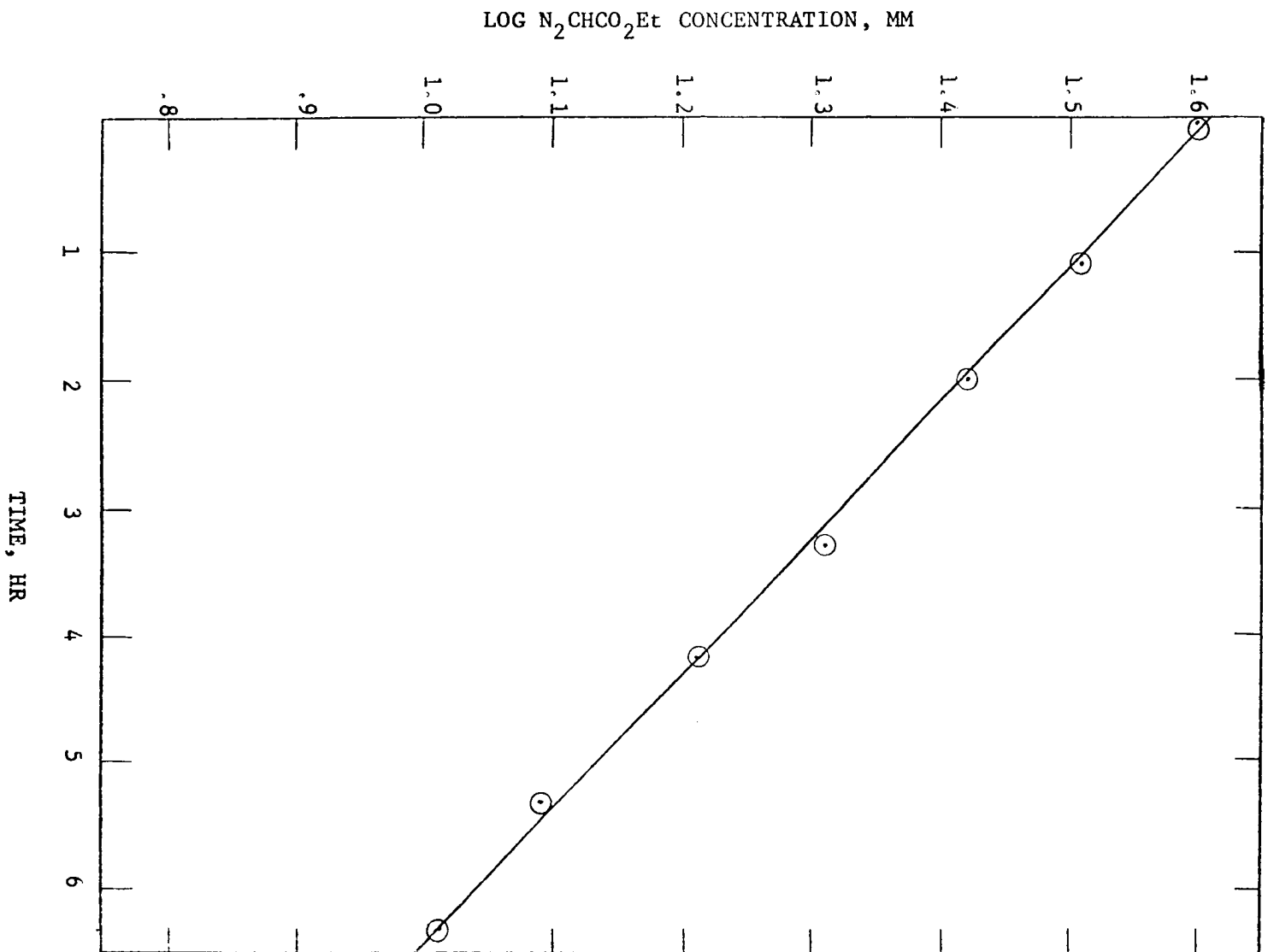
Figure 11. Plot of ethyl diazoacetate decomposition in CD_3CH_2Br vs. time at 10°.
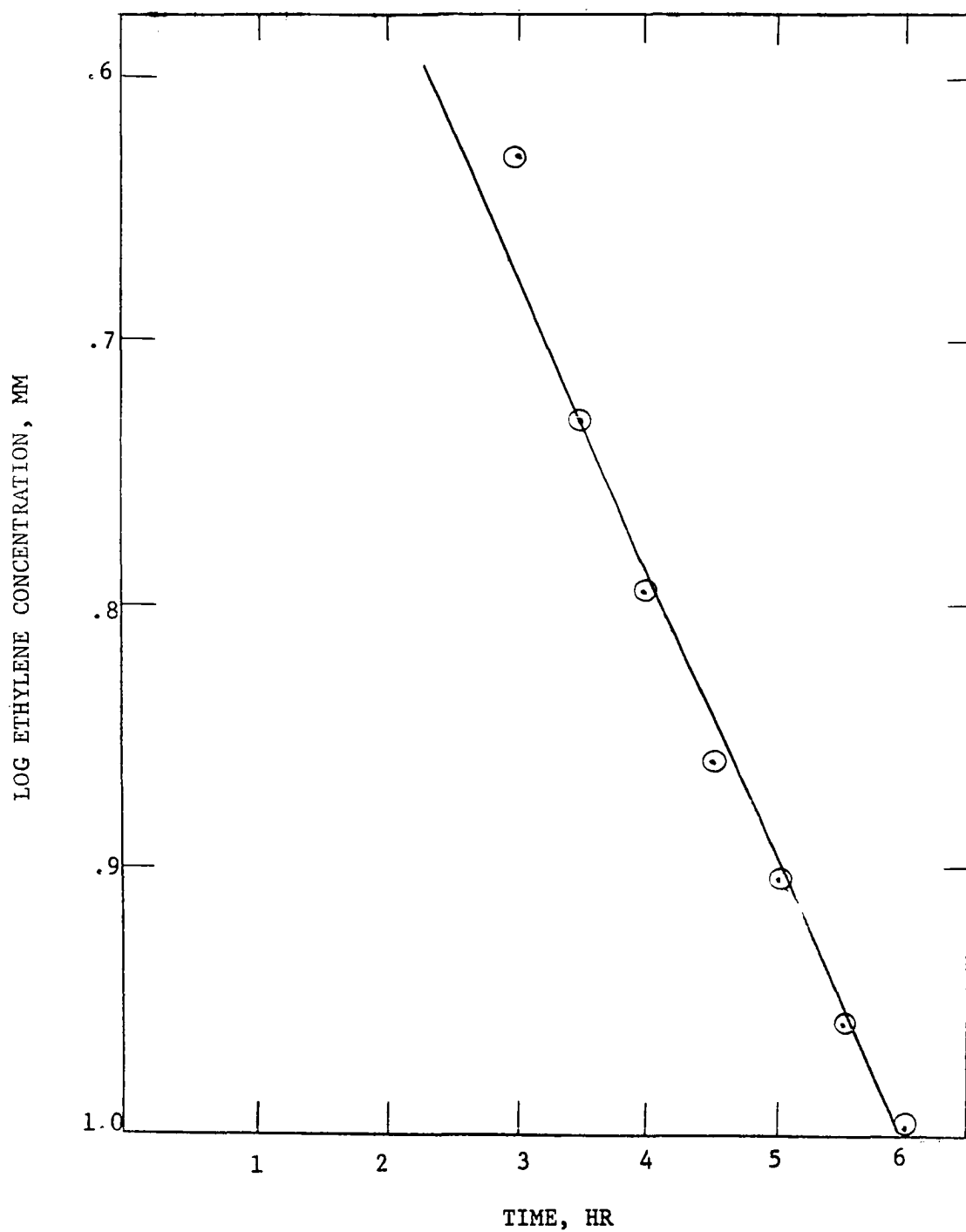
Figure 12. Plot of $CD_2{=}CH_2$ formation vs. time during ethyl diazoacetate photolysis in CD_3CH_2Br at $10°$.

for carbethoxycarbene, essentially equal amounts of $CH_2=CH_2$, $CD_2=CH_2$,

$BrCH_2CO_2Et$, and $Br\underset{D}{C}HCO_2Et$ formed.

CH_3CH_2Br ⟍

CD_3CH_2Br ⟋ ⟩ $:CHCO_2Et$ ⟶

$CH_2=CH_2$ $BrCH_2CO_2Et$

$CD_2=CH_2$ $Br\underset{D}{C}HCO_2Et$

$d_0/d_3 = 1.0$ $d_0/d_2 = .99\pm.04$ $d_0/d_1 = 1.02\pm.10$
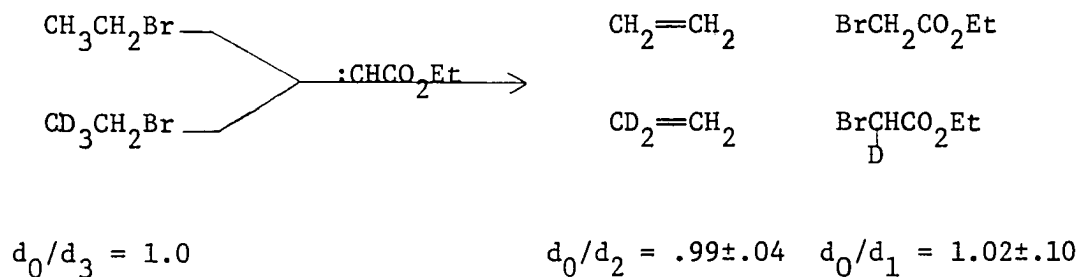
These results illustrate that a C-D bond in CD_3CH_2Br is just as

likely to be broken during the carbene induced elimination as is a C-H

bond in CH_3CH_2Br, telling us that substitution of heavy for light hydro-

gen does not affect the activation energy of the elimination process.

Stretching of a C-D bond is significantly more difficult than the stretch-

ing of an equivalent C-H bond. The activation process in the elimination

reaction must, therefore, involve very little if any stretching of the

C-H(D) bond.[172]

The cleavage of the C-X bond in the rate determining step suggests

that concomitant skeletal rearrangement of the alkyl moiety might be ex-

pected. Since neopentyl compounds are known to undergo facile rearrange-

ment,[173] neopentyl bromide was selected for examination. This compound

has no β-hydrogens. Direct β-elimination of HBr is, therefore, impossible.

Observation of the formation of $BrCH_2CO_2Et$ would suggest a pathway involv-

ing a skeletally rearranged intermediate.

$$CH_3\overset{\underset{\displaystyle CH_3}{|}}{\underset{\displaystyle |}{\overset{\displaystyle CH_3}{C}}}CH_2\text{-Br} \quad + \quad :CHCO_2Et \quad \longrightarrow \quad CH_3\overset{\underset{\displaystyle CH_3}{|}}{\underset{\displaystyle |}{\overset{\displaystyle CH_3}{C}}}CH_2^{\oplus} \quad BrCH=\overset{\overset{\displaystyle \ominus O}{|}}{C}\text{-OEt}$$

$$\xrightarrow[\sim CH_3:]{\text{1,2 shift}} \quad CH_3\text{-}\overset{\underset{\displaystyle CH_3}{|}}{\overset{\oplus}{C}}\text{-}\overset{\overset{\displaystyle H}{|}}{C}H\text{-}CH_3 \quad BrCH=\overset{\overset{\displaystyle \ominus O}{|}}{C}\text{-OEt} \quad \longrightarrow \quad \text{olefin} + BrCH_2CO_2Et$$
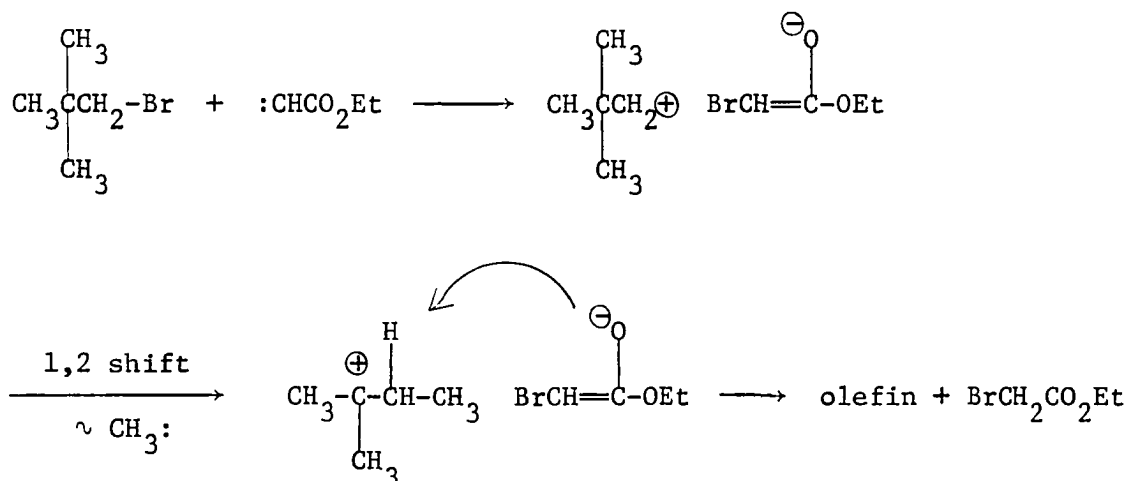
Vpc analysis, however, revealed no ethyl bromoacetate formation. The C-Br and C-H insertion products were formed in a ratio of $4.3\pm.3$ to 1, despite the statistical preponderance of C-H bonds.

$$CH_3\overset{\underset{\displaystyle CH_3}{|}}{\underset{\displaystyle |}{\overset{\displaystyle CH_3}{C}}}\text{-}CH_2\text{-Br} \quad + \quad \cancel{:CHCO_2Et}$$

$$\xrightarrow{\quad} BrCH_2CO_2Et \qquad 0$$

$$\xrightarrow{\text{C-Br insertion}} CH_3\overset{\underset{\displaystyle CH_3}{|}}{\overset{\displaystyle CH_3}{C}}CH_2\overset{\overset{\displaystyle CH_3}{|}}{\underset{\displaystyle Br}{C}}HCO_2Et \quad 4.3\pm.3$$

$$\xrightarrow{\text{C-H insertion}} BrCH_2\overset{\overset{\displaystyle CH_3}{|}}{\underset{\displaystyle CH_3}{C}}CH_2CH_2CO_2Et \quad 1$$
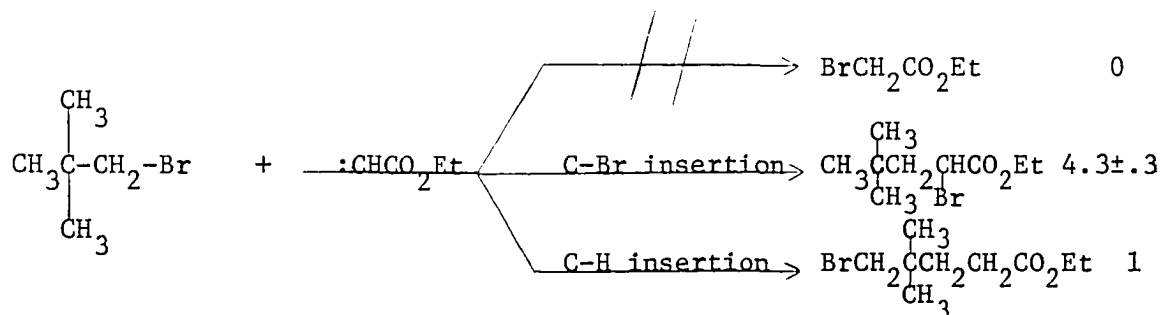
The observation of skeletal rearrangement in the reaction of carbethoxycarbene with neopentyl bromide would have constituted strong evidence for a carbonium ion like intermediate. Contrariwise, the failure to observe rearrangement is not compelling evidence against such an intermediate. The solvolysis reactions of neopentyl compounds, characterized by facile skeletal rearrangement,[173] involve free, solvent stabilized, dissociated carbonium ions in polar media. However, the behavior of a

tight carbonium ion pair in a relatively non-polar media (alkyl halide) might be expected to differ. In particular such a tight ion pair should be less prone to undergo skeletal rearrangement due to its shorter life-time and the appreciable electrostatic stabilization between the positive alkyl and the negative counteranion.[170] (For further evidence supporting the view that tight ion pairs in non polar media are less subject to undergo skeletal rearrangement, see Part II of this dissertation.)

The bond reactivity order C-I > C-Br > C-Cl >>> C-F; the linear relationship of C-X bond reactivity with bond strength analogous to carbonium ion reactions; the isotope effect studies indicating little if any stretching of the C-H(D) bond in the transition state; and the lack of skeletal rearrangement involving neopentyl bromide; suggest initial C-X bond cleavage with formation of a tight carbonium ion pair intermediate which collapses very rapidly with preferential β-proton loss to form elimination products or (in the absence of available protons) to form C-Br insertion product.

INFLUENCE OF PARAMETERS:

In an attempt to gain insight into the nature of carbethoxycarbene behavior with simple alkyl halides, control studies were made to ascertain the effect of various parameters.

The effect of structural variation of the substrate was determined by studying a series of 1°, 2°, and 3° alkyl halides. Compounds studied and yields of elimination product included: ethyl chloride $30.8\pm.2\%$, ethyl bromide $41.2\pm1.5\%$, ethyl iodide $32.5\pm.5\%$, isopropyl chloride $36.7\pm.5\%$, isopropyl bromide 38.3%, isopropyl iodide $40.6\pm1.6\%$, sec-butyl chloride $32.6\pm.3\%$, sec-butyl bromide $37.1\pm.3\%$, sec-butyl iodide $37.3\pm3\%$, t-butyl chloride $30.6\pm1.2\%$, t-butyl bromide $38.6\pm.1\%$, and t-butyl iodide $33.9\pm.3\%$. Thus, despite these significant structural variations the amount of elimination stayed within the narrow range of 30-40%. Furthermore, no significant change occurred in the amount of insertion products formed, i.e., ca. 5%.

Increasing the concentration from .80 to 1.6 molar decreased $BrCH_2CO_2Et$ formation by only 11%; whereas, decreasing the concentration from .80 to .016 molar increased the yield by only 10%.

Since carbethoxycarbene can theoretically exist in either the singlet or triplet form and, thus, in different energy states,[24] a change in reaction temperature might be capable of exerting an influence on the reaction with alkyl halide. Thus, if the temperature were lowered appreciably a crossover from singlet to triplet (or vice versa) might be induced and, subsequently, affect the elimination product yield or, possibly, increase insertion reaction. Actually, however, when the photolysis was conducted at -50°, the usual yield of ca. 40% Br CH_2CO_2Et was obtained.

Similarly, a variation in the wavelength (energy) of the incident light could conceivably favor singlet over triplet (or vice versa) and, thus, affect the observed reaction behavior.[174-177] Usually employed was a 200 watt Hanovia medium pressure lamp with a Pyrex filter and, thus, light of 3000-4000 A^o. Removal of the Pyrex filter, 2000-3000 A^o light, decreased the absolute yield of elimination product by only 6%. Use of either a 275 watt General Electric sunlamp or an ordinary 1500 watt light bulb resulted in the usual yield of ca. 40%; whereas, an Ultra Violet Products low pressure immersion lamp caused an 11% decrease in absolute yield.

Dilution of the usual .80 molar ethyl diazoacetate alkyl halide solution with an equal volume of benzene, acetone, or cyclohexane resulted in a 17% decrease in elimination. The solvents acetonitrile, ethanol, and Freon E-1 were unsatisfactory due to vpc analysis complications while perfluoro-kerosene was unsatisfactory due to insolubility. Further experiments involving photolysis of ethyl diazoacetate in ethyl bromide-cyclohexane mixtures and subsequent quantitative analysis, revealed that the C-Br bond in ethyl bromide was 15.8±1.2 times as reactive toward carbethoxycarbene as a C-H bond in cyclohexane.

However, conditions and alkyl substrates were found that afforded no elimination. Thus, elimination failed to occur when ethyl diazoacetate was refluxed in ethyl bromide for 48 hours (i.e., no decomposition of ethyl diazoacetate). Use of powdered copper catalyst produced only ethyl maleate and ethyl fumarate. Photolysis of ethyl diazoacetate in neopentyl bromide, benzyl chloride, iodobenzene, and 1-fluorohexane formed no XCH_2CO_2Et products.

For the effect of oxygen, nitrogen, and benzophenone on the reaction, see the discussion under SINGLET OR TRIPLET.

The insensitivity of carbethoxycarbene induced elimination to 1°, 2°, and 3° alkyl halide structural variations, temperature, concentration, oxygen, and wavelength together with the ability to compete well with other reactions in the presence of solvent illustrate the extremely facile nature of the elimination reaction. General limitations imposed are reflected in the lack of elimination at moderate temperature, in the presence of catalyst, with alkyl fluoride, with aromatic halide, and alkyl halides with no β-hydrogens.

CIS OR TRANS ELIMINATION:

In order to ascertain the stereochemistry of HX elimination an investigation was made using 1-bromo-2-deuterioindane as the substrate. This compound was prepared by the method of Dewar and Fahey.[178] Thus, deuterium bromide was reacted with indene at -78° in pentane solvent. The product consisted of 80% cis and 20% trans adduct, as determined by nmr peak height measurements (Figure 13).[179]

A solution containing ethyl diazoacetate and 1-bromo-2d-indane (80% cis, 20% trans) was placed in a Pyrex vessel and photolyzed at 25° using a 275 watt General Electric Sunlamp. The ethyl bromoacetate product was collected via vpc with plans to determine the deuterium content from the mass spectrum (which would subsequently allow the stereochemical course of elimination to be determined).

At this point it was discovered that the 80% cis, 20% trans 1-bromo-2d-indane was capable of equilibrating readily to a 50/50 mixture (Figure 14). At room temperature this occurred within 24 hours. This previously unrecognized fact obviously negated the results of our experiments, since equilibration was occurring faster than reaction with carbethoxycarbene. Numerous attempts to carry out the photolysis at reduced temperature (to retard the thermal isomerization toward 50/50 composition) were unsuccessful.
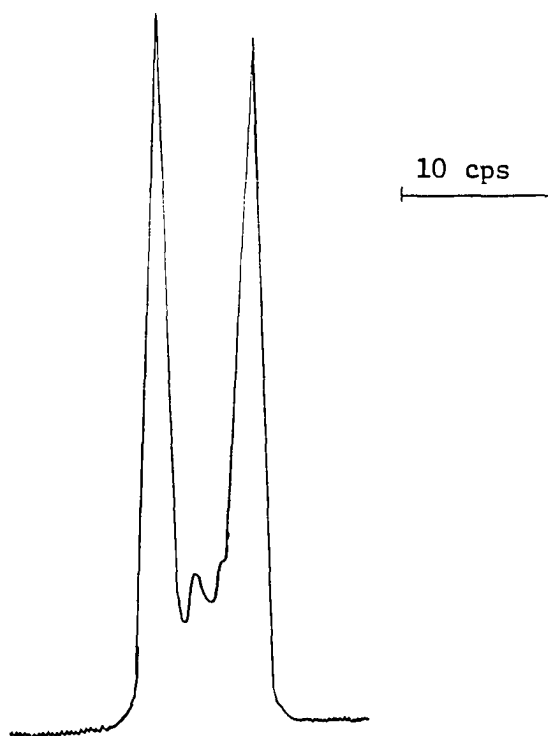
Figure 13.   CHBr proton of 1-bromo-2-deuterionindane of 80% <u>cis</u>, 20%

trans composition.
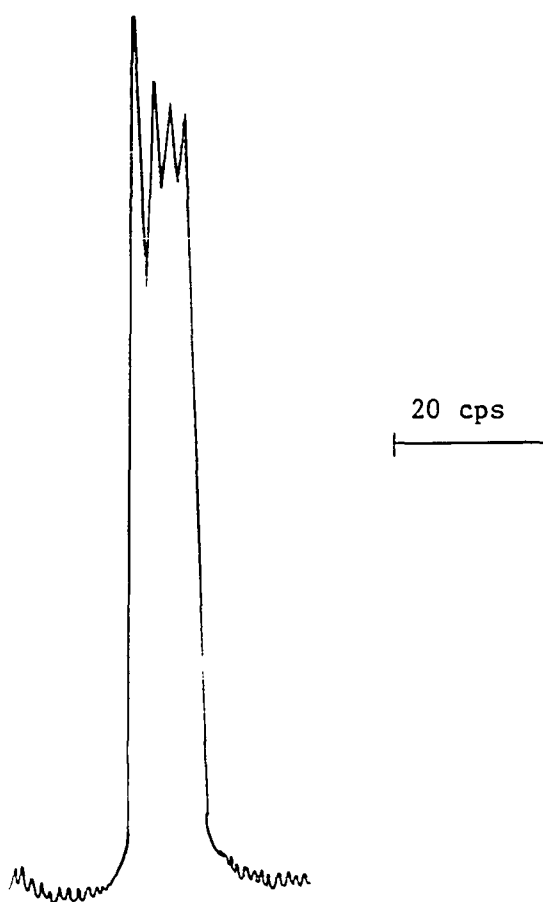
Figure 14.   CHBr proton of 1-bromo-2-deuterioindane of 50% cis, 50%

trans composition.

Since addition and elimination reactions in the bicyclo-[2.2.2]-octyl system have not been studied extensively, we initiated some work in this area (see Part II of this dissertation for further elaboration). Our primary goal was to obtain an alkyl halide substrate that would allow the stereochemistry of carbethoxycarbene induced HX elimination to be determined. Deuterium bromide was added to bicyclo-[2.2.2]-octene at $-78°$ in pentane solvent. The product, 2-bromo-3-deuterobicyclo-[2.2.2]-octane, consisted of 80% cis and 20% trans adduct, as determined by nmr peak height measurements (Figure 15).
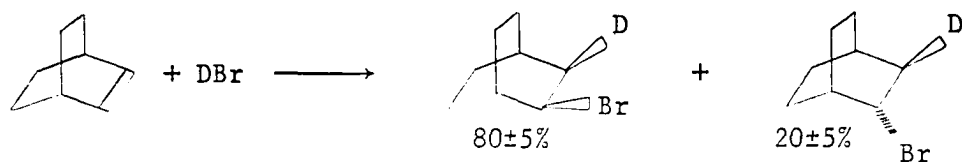
Next, solutions of ethyl diazoacetate and 2-bromo-3d-bicyclo-[2.2.2]-octane were prepared and photolyzed at $25°$ using a 275 watt General Electric Sunlamp. The ethyl bromoacetate and bicyclo-[2.2.2]-octene products were collected via vpc in order to determine the deuterium content via subsequent mass spectrometric analysis.

DECOUPLED

20 cps
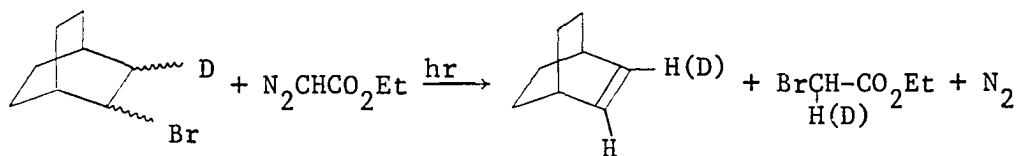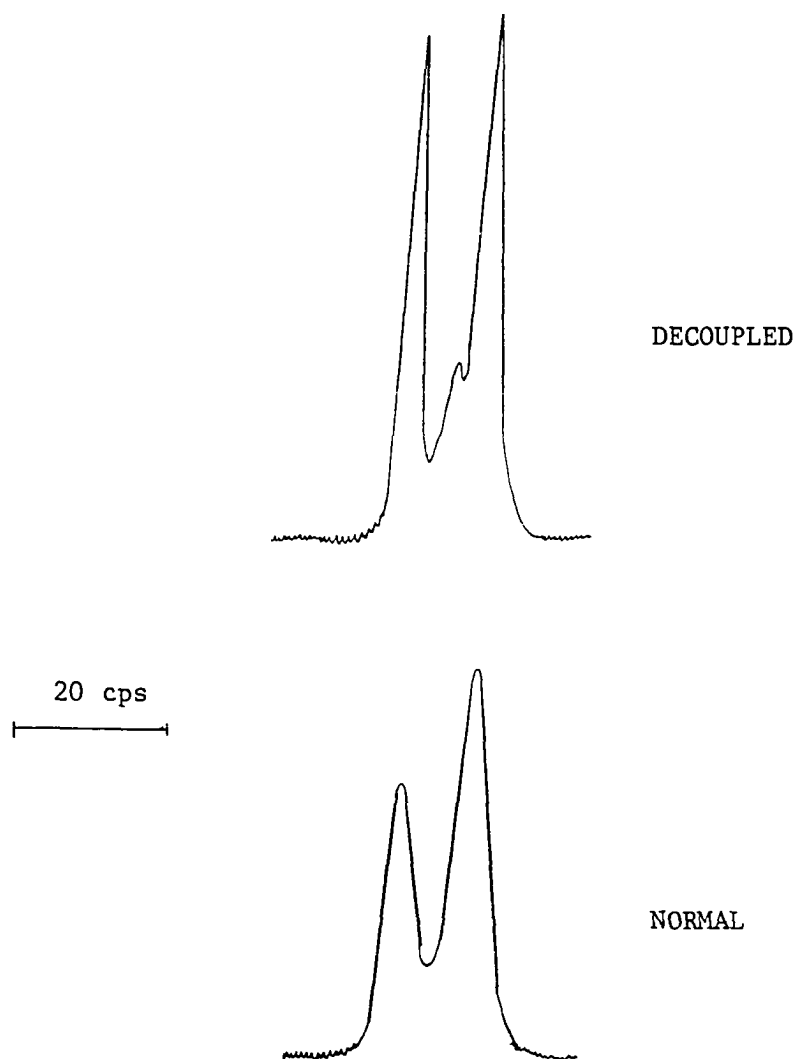
NORMAL

Figure 15. CHBr proton of 2-bromo-3-d-bicyclo[2.2.2]octane of 80% cis,
20% trans composition: bottom, normal; top, decoupled.

The ethyl bromoacetate product was found to contain $32.6 \pm 1.0\%$ d_o and $67.4 \pm 1.0\%$ d_1, indicative of $80 \pm 7\%$ <u>cis</u> and $20 \pm 7\%$ <u>trans</u> elimination; whereas, the other elimination product, bicyclo-[2.2.2]-octene, contained $66.0 \pm 2.7\%$ d_o and $34.0 \pm 2.7\%$ d_1, indicative of $78 \pm 9\%$ <u>cis</u> and $22 \pm 9\%$ <u>trans</u> elimination. These results were obtained from six independent runs and firmly establish the preference for <u>cis</u> elimination.

Furthermore, it was ascertained that the substrate was not inherently prejudiced toward <u>cis</u> elimination since under typical E2 conditions (concentrated potassium t-butoxide in refluxing t-butyl alcohol) $24 \pm 7\%$ <u>cis</u> and $76 \pm 7\%$ <u>trans</u> elimination occurred. In some rigid systems such as bicyclo-octyl, norbornyl, etc., the dihedral angle for <u>cis</u> elimination is <u>ca.</u> $0°$, while for <u>trans</u> the angle is <u>ca.</u> $120°$.[180] The usual driving force for <u>trans</u> elimination (coplanar $180°$ angle[181]) is, therefore, absent. Such systems under E2 conditions usually seem to prefer to undergo <u>cis</u> HX elimination.[182,183] Dr. M.J.S. Dewar,[184] however, suggested that the bicyclo-octyl bromide system might be flexible enough to assume a coplanar $180°$ orientation of H and X in the transition state and, thus, he correctly predicted our observed predominant <u>trans</u> elimination mode under E2 conditions.

Carbethoxycarbene's stereoselective (not stereospecific) <u>cis</u> elimination of hydrogen halide from a system not inherently prejudiced toward <u>cis</u> elimination is indicative of a step-wise rather than concerted mechanism (a single elementary step would have to be stereospecific[185]). This result is consistent with a tight carbonium ion pair intermediate which collapses, preferably but not exclusively, with <u>cis</u> β-proton removal.

SUMMARY AND CONCLUSIONS

Simple monohaloalkanes with available β-hydrogen have been found
to react with photolytically generated carbethoxycarbene to form HX eli-
mination products to the extent of almost complete exclusion of insertion
products. The insensitivity of carbethoxycarbene induced elimination to
1°, 2°, and 3° alkyl halide structural variations, temperature, concen-
tration, oxygen, and wavelength, together with the ability to compete
well with other reactions in the presence of solvent, illustrate the ex-
tremely facile nature of the elimination reaction. General limitations
imposed are reflected in the lack of elimination at moderate temperature
(without light), in the presence of catalyst, with alkyl fluoride, with
aromatic halide, and alkyl halides with no β-hydrogens.

A mechanism involving unimolecular loss of HBr from ethyl bromide
was considered. However, the inertness of pure ethyl bromide to our
standard reaction conditions; the failure of the chosen sensitizer, ben-
zophenone, to induce loss of HBr from ethyl bromide; and the theoretical
implications involved in forming electronically excited ethyl bromide;
suggest that unimolecular loss of HBr does not occur in our photolysis
of ethyl diazoacetate in alkyl halides.

An investigation was made to determine if C-Br insertion product
was a transient intermediate leading to the observed products (olefin
plus ethyl bromoacetate) in the reaction of carbethoxycarbene with ethyl

-67-

bromide. However, the inertness of ethyl α-bromobutyrate in ethyl bromide solution to our standard reaction conditions; the failure of the chosen benzene sensitizer to induce ethyl α-bromobutyrate to undergo Norrish Type II photoelimination; and the failure under our standard reaction conditions of ethyl α-bromobutyrate added to an ethyl bromide solution of ethyl diazoacetate to increase the total amount of ethyl bromoacetate produced; rule out any mechanism involving transient, electronically excited ethyl α-bromobutyrate as an intermediate. Furthermore, theoretical implications concerning the fate of any initially formed, vibrationally excited ethyl α-bromobutyrate, suggest the high probability that it is not an intermediate leading to our observed products.

A substrate, CD_3CH_2Br, was selected in order to determine whether the carbene induced elimination of hydrogen halide was an α or β process. The formation of d_2-ethylene (no d_3-ethylene) and d_1-ethyl bromoacetate (no d_0-ethyl bromoacetate) in the reaction of carbethoxycarbene with CD_3CH_2Br rules out even the partial participation of an α-elimination pathway. Thus, preference for a β-elimination mode has been firmly established for systems with available β-protons. The failure of the two substrates without β-protons to yield elimination products suggests that in general not only is α-elimination less favorable but in fact altogether impossible for such monohalo substrates.

Carbethoxycarbene is theoretically capable of existing in either the singlet (spins paired) or triplet (spins unpaired) form. The general literature concerning the photolysis of ethyl diazoacetate and other diazo carbonyl compounds; the stereospecific addition of carbethoxycarbene to olefins; the dramatic reduction in yield of ethyl bromoacetate under the

conditions favoring triplet formation; the slight effect of O_2 on carbethoxycarbene reaction in cyclohexane; and the slight effect of O_2 on carbethoxycarbene reaction in ethyl bromide; strongly indicate that singlet :$CHCO_2Et$ is the reactive species involved in the induced elimination of hydrogen halide from alkyl halides.

Consideration was given as to whether the C-H and C-X bonds broke at the same time or in a step-wise fashion. The bond reactivity order C-I > C-Br > C-Cl >>> C-F; the linear relationship of C-X bond reactivity with bond strength analogous to carbonium ion reactions; the isotope effect studies indicating little if any stretching of the C-H(D) bond in the transition state; the lack of skeletal rearrangement involving neopentyl bromide; and the stereoselective (not stereospecific) cis elimination of hydrogen halide from a system not inherently prejudiced toward cis elimination; suggest initial slow C-X bond cleavage with formation of a tight carbonium ion pair intermediate which collapses very rapidly with preferential cis β-proton loss to form elimination products or (in the absence of available β-protons) to form C-X insertion product.

The overall experimental and theoretical aspects of our study suggest, and are consistent with, the postulated general mechanism depicted in Figure 16 for the reaction of photolytically generated carbethoxycarbene with monohaloalkanes.

olefin + XCH$_2$CO$_2$Et   olefin + XCH$_2$CO$_2$Et

ca. 20% trans β-   ca. 80% cis β-
proton removal   proton removal

N$_2$CHCO$_2$Et $\xrightarrow{\text{slow (overall rate determining step)}}$ N$_2$ + :CHCO$_2$Et

major path

R-X: fast   slow   fast | minor path   R-CH-CO$_2$Et
                                                                              |
                                                                              X

:CH—C-OEt   R—X—CH-C-OEt   R ⊕   X-C-C-OEt
HC=C-OEt   R—X—CH=C-OEt   R ⊕   X-C=C-Et

tight ion pair
intermediate
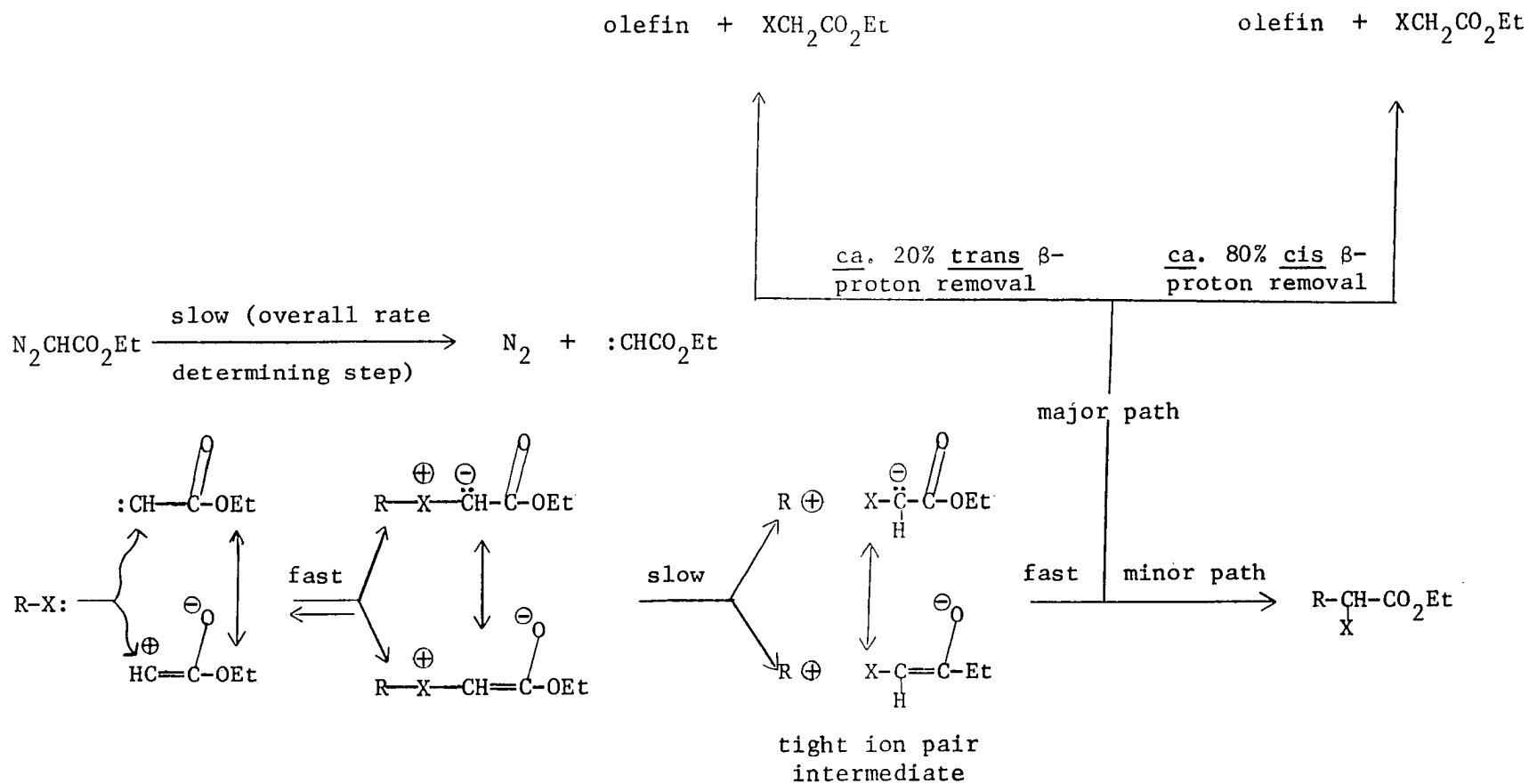
Figure 16.   Mechanism for the reaction of photolytically generated carbethoxycarbene with monohaloalkanes.

EXPERIMENTAL

<u>Materials and Methods</u>.   Chemicals used and their suppliers are
listed below.

Acetone, reagent grade, Fisher
Acetonitrile, practical grade, MC&B
Benzene, reagent grade, Fisher
Benzophenone, highest purity grade, Eastman
Benzyl chloride, highest purity grade, Eastman
Bromine, reagent grade, Curtin
2-Bromobutane, reagent grade, Eastman
2-Bromopropane, reagent grade, Eastman
$\underline{t}$-Butyl bromide, reagent grade, Eastman
$\underline{t}$-Butyl chloride, reagent grade, Eastman
$\underline{t}$-Butyl iodide, reagent grade, Eastman
2-Chlorobutane, reagent grade, Eastman
2-Chloropropane, reagent grade, Eastman
Cobalt sulfate, reagent grade, Fisher
Copper, fine powder, B&A
Cyclohexane, reagent grade, Fisher
Deuterium oxide, 99.8% pure, Diaprep, Inc.
1,2-Dibromoethane, Fisher
Drierite, W. A. Hammond Drierite Co.
Ethyl bromide, highest purity grade, MC&B
Ethyl bromoacetate, highest purity grade, MC&B
Ethyl α-bromobutyrate, reagent grade, Eastman
Ethyl β-bromobutyrate, Columbia Organic Chemicals
Ethyl γ-bromobutyrate, reagent grade, Baker
Ethyl chloride, reagent grade, Eastman
Ethyl chloroacetate, highest purity grade, MC&B
Ethyl cyclohexylacetate, Aldrich
Ethyl ether, anhydrous, reagent grade, Mallincrodt
Ethyl fluoroacetate, Columbia Organic Chemicals
Ethyl fumarate, MC&B
Ethyl iodide, reagent grade, Eastman
Ethyl iodoacetate, practical grade, Eastman
Ethyl maleate, reagent grade, Eastman
Ethyl phenylacetate, reagent grade, Eastman
1-Fluorohexane, reagent grade, Eastman
Glycine ethyl ester hydrochloride, reagent grade, Eastman

Hexafluorobenzene, Columbia Organic Chemicals
Hydrobromic acid, 48% aqueous, reagent grade, Baker
Hydrochloric acid, reagent grade, Baker
Indene, reagent grade, K&K
Iodobenzene, reagent grade, Eastman
2-Iodobutane, reagent grade, Eastman
2-Iodopropane, reagent grade, Eastman
Lithium aluminum hydride, Metal Hydrides, Inc.
Magnesium sulfate, anhydrous, B&A
Methylene chloride, highest purity grade, MC&B
Neopentyl bromide, Columbia
Nickel sulfate, reagent grade, Baker
Phosphorus tribromide, practical grade, Eastman
Sodium bicarbonate, reagent grade, Fisher
Sodium nitrite, reagent grade, B&A
Sulfuric acid, reagent grade, Fisher
Tetradeuteroacetic acid, 99%, Columbia

Gas chromatography work was performed using Varian Aerograph Model 90-P and Model A-700 instruments with thermal conductivity detectors. Both employed helium carrier gas. Infrared spectra were recorded using a Beckman IR8 Spectrophotometer. Nuclear magnetic resonance spectra were recorded on a Varian A-60 Spectrophotometer equipped with a spin decoupler and using tetramethyl silane as the internal standard. Mass spectra were recorded by Dr. A. P. Marchand and Mr. Mike Wilson.

Ethyl Diazoacetate. An adaptation of the improved method of N. E. Searle[2] was used to prepare ethyl diazoacetate. Thus, a solution of 140 g (1 mole) of glycine ethyl ester hydrochloride in 250 ml of water was mixed with 600 ml of methylene chloride in a 2 liter round bottom flask fitted with a stirrer, dropping funnel, and thermometer. The solution was cooled to -5° (using an acetone bath with added Dry Ice) and a cold solution of 83 g (1.2 moles) of sodium nitrite in 250 ml of water added with stirring. The temperature was lowered to -10° and 100 ml of 5% sulfuric acid was added from the dropping funnel. Care was taken not

to allow the reaction temperature to rise above 5°. After about 15 minutes the reaction mixture was transferred to a 2 liter separatory funnel and the layers separated. The aqueous layer was extracted with 100 ml of methylene chloride. The combined organic solutions were washed with 1 liter of cold 5% sodium bicarbonate. After drying over 50 g of anhydrous magnesium sulfate and filtering, a rotary evaporator was used to remove methylene chloride under vacuum over a period of 24 hours in the dark at room temperature. This material was stable indefinitely if stored cold in the dark.

Preparations on half and double this scale were also made and yields of 75-85% obtained. The product had a refractive index of n_D^{27} 1.4610 (lit. n_D^{25} 1.4616)[2] and was determined to have a purity of 97±2%.

Three methods (nmr integration, azometric analysis, and vpc analysis) were used to determine the purity. The nmr spectrum indicated the presence of methylene chloride. Azometric analysis was performed by adding dilute hydrochloric acid to an aliquot of ethyl diazoacetate and comparing the amount of nitrogen evolved with the theoretical. Vpc analysis was performed using a 10 ft. x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80 operating at 130°, helium flow rate 150 cm^3/min. The area per cent of ethyl diazoacetate reflected its approximate purity and methylene chloride plus ethyl chloroacetate, identified on the basis of retention time, were impurities present.

Further purification via reduced pressure fractional distillation was found to be inadvisable due to the already high purity as determined above and the difficulty and inherent danger involved.[2]

STANDARD PROCEDURE:

Photolysis of Ethyl Diazoacetate in Alkyl Halide Solution. A 50 ml
(.80 molar) solution of ethyl diazoacetate (40 mm) in alkyl halide was pre-
pared. This solution was photolyzed for 22 hours with a 200 watt medium
pressure Hanovia UV Lamp. The lamp was enclosed in a Pyrex 7740 sleeve,
the top and bottom of which were stoppered to prevent any unfiltered light
from reaching the solution. This lamp assembly rested within a quartz
double-walled Hanovia Immersion Well. The immersion well was immersed in
the solution to be photolyzed. The capacity of the cylindrical solution
vessel was ca. 50 ml and was equipped with a thermometer and side arm.
Cooling was provided by circulating water from a large cold bath (set at
$0°$) through the jacket of the immersion well. This allowed the tempera-
ture of the reaction solution to remain at $10\pm1°$.

After the reaction was complete excess volatile solvent was usually
removed on a rotary evaporator at room temperature under vacuum. The con-
centrate had appreciable waxy insoluble material, presumably polymeric
$(H-\overset{|}{C}-CO_2Et)_n$ which failed to elute via vpc. No dimer was present.

Analyses were usually performed on a 20 ft. x 3/8" glass column
packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80
usually operating at $140°$ with varied helium flow rates.

Identifications were based on retention times and comparison of ir,
nmr, and n_D of collected material with authentic samples.

Absolute product yields were obtained by peak area measurements
utilizing an internal standard. Areas were calculated by multiplying
the peak height by the width at half height. Standard solutions were
employed to obtain correction factors needed to correlate area per cent

with weight per cent. The product balance unaccounted for by vpc was attributed to the previously mentioned unidentified polymer which failed to elute.

Photolysis of Ethyl Diazoacetate in Ethyl Bromide. See standard procedure for photolysis of ethyl diazoacetate in alkyl halide solution. Five runs were made and $2.76 \pm .10$ g ($16.5 \pm .6$ mm, $41.2 \pm 1.5\%$) of ethyl bromoacetate formed. Also present were ethyl α-bromobutyrate, ethyl β-bromobutyrate, and ethyl γ-bromobutyrate (the C-Br, αC-H, and βC-H insertion products). The total amount of insertion products was ca. 5%.

As ethyl diazoacetate was being decomposed by the UV light the evolved gas was bubbled through a carbon tetrachloride solution of bromine. Thus the other elimination product, ethylene, was trapped as 1,2-dibromoethane.

Vpc analysis was performed on a Varian Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 10% Dibuty Tetrachloropthalate on Chromsorb W. Regular 60/80, operating at 119°, detector 157°, filament current 100 ma, halium flow rate 600 cm^3/min. The internal standard used was ethyl β-bromobutyrate. The following correlation between area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl } \beta\text{-bromobutyrate}} \times 1.03 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl } \beta\text{-bromobutyrate}}$$

Photolysis of Ethyl Diazoacetate in Ethyl Chloride. See standard procedure for photolysis of ethyl diazoacetate in alkyl halide solution. Two runs were made and 1.49-1.52 g (12.2-12.4 mm, $30.8 \pm .2\%$) of ethyl chloroacetate formed. Other peaks present to the extent of ca. 5% were presumably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 142°, detector 169°, filament current 100 ma, helium flow rate 600 cm^3/min. The internal standard used was ethyl bromoacetate. The following correlation between area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl chloroacetate}}{\text{Area of ethyl bromoacetate}} \times .74 = \frac{\text{Weight of ethyl chloroacetate}}{\text{Weight of ethyl bromoacetate}}$$

Photolysis of Ethyl Diazoacetate in Ethyl Iodide. See standard procedure for photolysis of ethyl diazoacetate in alkyl halide solution. Two runs were made and 2.74-2.83 g (12.8-13.2 mm, 32.5±.5%) of ethyl iodoacetate formed. Other peaks present to the extent of ca. 5% were presumably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 15% SE 30 on Chromsorb W Regular 60/80, operating at 135°, detector 159°, filament current 100 ma, helium flow rate 100 cm^3/min. The internal standard used was ethyl bromoacetate. The following correlation between area and millimole ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl iodoacetate}}{\text{Area of ethyl bromoacetate}} = \frac{\text{Millimoles of ethyl iodoacetate}}{\text{Millimoles of ethyl bromoacetate}}$$

Photolysis of Ethyl Diazoacetate in 2-Bromopropane. See standard procedure for photolysis of ethyl diazoacetate in alkyl halide solution Two runs were made and 2.55-2.56 g (15.3 mm, 38.3%) of ethyl bromoacetate formed. Other peaks present to the extent of ca. 5% were presumably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chroma-
tograph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetra-
chloropthalate on Chromsorb W. Regular 60/80, operating at 143°, detector
158°, filament current 100 ma, helium flow rate 600 cm^3/min. The in-
ternal standard used was ethyl β-bromobutyrate. The following correlation
between area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.17 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Photolysis of Ethyl Diazoacetate in 2-Chloropropane. See standard
procedure for photolysis of ethyl diazoacetate in alkyl halide solution.
Two runs were made and 1.78-1.82 g (14.5-14.9 mm, 36.7±.5%) of ethyl chloro-
acetate formed. Other peaks present to the extent of ca. 5% were presumably
the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chromato-
graph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloro-
pthalate on Chromsorb W Regular 60/80, operating at 142°, detector 168°,
filament current 100 ma, helium flow rate 600 cm^3/min. The internal
standard used was ethyl bromoacetate. The following correlation between
area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl chloroacetate}}{\text{Area of ethyl bromoacetate}} \times .84 = \frac{\text{Weight of ethyl chloroacetate}}{\text{Weight of ethyl bromoacetate}}$$

Photolysis of Ethyl Diazoacetate in 2-Iodopropane. See standard
procedure for photolysis of ethyl diazoacetate in alkyl halide solution.
Two runs were made and 3.34-3.62 g (15.6-16.9 mm, 40.6±1.6%) of ethyl
iodoacetate formed. Other peaks present to the extent of ca. 5% were
presumably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 15% SE 30 on Chromsorb W Regular 60/80, operating at 135°, detector 159°, filament current 100 ma, helium flow rate 100 cm^3/min. The internal standard used was ethyl bromoacetate. The following correlation between area and millimole ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl iodoacetate}}{\text{Area of ethyl bromoacetate}} = \frac{\text{Millimoles of ethyl iodoacetate}}{\text{Millimoles of ethyl bromoacetate}}$$

Photolysis of Ethyl Diazoacetate in 2-Bromobutane. See standard procedure for photolysis of ethyl diazoacetate in alkyl halide solution. Two runs were made and 2.46-2.50 g (14.7-15.0 mm, 37.1±.3%) of ethyl bromoacetate formed. Other peaks present to the extent of ca. 5% were presumably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 142°, detector 170°, filament current 100 ma, helium flow rate 600 cm^3/min. The internal standard used was ethyl β-bromobutyrate. The following correlation between area and millimole ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.18 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Photolysis of Ethyl Diazoacetate in 2-Chlorobutane. See standard procedure for photolysis of ethyl diazoacetate in alkyl halide solution. Two runs were made and 1.58-1.61 g (12.9-13.2 mm, 32.6±.3%) of ethyl chloroacetate formed. Other peaks present to the extent of ca. 5% were presumably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 141°, detector 165°, filament current 100 ma, helium flow rate 600 cm^3/min. The internal standard used was ethyl bromoacetate. The following correlation between area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl chloroacetate}}{\text{Area of ethyl bromoacetate}} \times .71 = \frac{\text{Weight of ethyl chloroacetate}}{\text{Weight of ethyl bromoacetate}}$$

Photolysis of Ethyl Diazoacetate in 2-Iodobutane. See standard procedure for photolysis of ethyl diazoacetate in alkyl halide solution. Two runs were made and 2.93-3.45 g (13.7-16.1 mm, 37.3±3%) of ethyl iodoacetate formed. Other peaks present to the extent of ca. 5% were presumably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 15% SE 30 on Chromsorb W Regular 60/80, operating at 135°, detector 159°, filament current 100 ma, helium flow rate 100 cm^3/min. The internal standard used was ethyl bromoacetate. The following correlation between area and millimole ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl iodoacetate}}{\text{Area of ethyl bromoacetate}} = \frac{\text{Millimoles of ethyl iodoacetate}}{\text{Millimoles of ethyl bromoacetate}}$$

Photolysis of Ethyl Diazoacetate in t-Butyl Bromide. See standard procedure for photolysis of ethyl diazoacetate in alkyl halide solution. Two runs were made and 2.54-2.59 g (15.4-15.5 mm, 38.6±.1%) of ethyl bromoacetate formed. Other peaks present to the extent of ca. 5% were presumably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chromato-graph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloro-pthalate on Chromsorb W Regular 60/80, operating at 145°, detector 170°, filament current 100 ma, helium flow rate 600 cm^3/min. The internal standard used was ethyl β-bromobutyrate. The following correlation be-tween area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.16 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Photolysis of Ethyl Diazoacetate in t-Butyl Chloride. See standard procedure for photolysis of ethyl diazoacetate in alkyl halide solution. Two runs were made and 1.44-1.56 g (11.8-12.7 mm, 30.6±1.2%) of ethyl chloro-acetate formed. Other peaks present to the extent of ca. 5% were presumably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chromato-graph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloro-pthalate on Chromsorb W Regular 60/80, operating at 141°, detector 170°, filament current 100 ma, helium flow rate 600 cm^3/min. The internal stan-dard used was ethyl bromoacetate. The following correlation between area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl chloroacetate}}{\text{Area of ethyl bromoacetate}} \times .75 = \frac{\text{Weight of ethyl chloroacetate}}{\text{Weight of ethyl bromoacetate}}$$

Photolysis of Ethyl Diazoacetate in t-Butyl Iodide. See standard procedure for photolysis of ethyl diazoacetate in alkyl halide solution. Two runs were made and 2.87-2.93 g (13.4-13.7 mm, 33.9±.3%) of ethyl iodo-acetate formed. Other peaks present to the extent of ca. 5% were presum-ably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chromato-
graph using a 20' x 3/8" glass column packed with 15% SE 30 on Chromsorb
W Regular 60/80, operating at 135°, detector 159°, filament current 100 ma,
helium flow rate 100 ml/min. The internal standard used was ethyl bromo-
acetate. The following correlation between area and millimole ratios was
found employing a standard solution.

$$\frac{\text{Area of ethyl iodoacetate}}{\text{Area of ethyl bromoacetate}} = \frac{\text{Millimoles of ethyl iodoacetate}}{\text{Millimoles of ethyl bromoacetate}}$$

Photolysis of Neat Ethyl Bromide. The standard procedure for
photolysis of ethyl diazoacetate in alkyl halide solution was used except
ethyl diazoacetate was omitted. No change could be detected after pho-
tolysis. Thus, the solution was not acidic to moist litmus indicating
no HBr formation and vpc analysis showed only the ethyl bromide peak.

When the photolysis was performed in the same way except with the
Pyrex filter omitted changes were detected. Thus, the solution was
acidic to moist litmus and HBr fumes were apparent. Furthermore, vpc
analysis revealed a peak other than ethyl bromide. This compound was
collected and identified as 1,2-dibromoethane.

Both HBr and 1,2-dibromoethane were formed even when a Pyrex fil-
ter was employed if the photolysis was continued for very long periods
(100 hours) or if the amount of ethyl bromide being irradiated was in-
creased substantially (750 ml).

Vpc analysis was performed on a Varian Model 90-P gas chromato-
graph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloro-
pthalate on Chromsorb W Regular 60/80, operating at 130°, detector 160°,
filament current 100 ma, helium flow rate 60 cm^3/min.

Photolysis of Ethyl α-Bromobutyrate in Ethyl Bromide. The stan-
dard procedure for the photolysis of ethyl diazoacetate in alkyl halide
solution was used except that no ethyl diazoacetate was used, only ethyl
bromide and 2.66 g (13.6 mm) of ethyl α-bromobutyrate. Vpc analysis re-
vealed that no ethyl bromoacetate formed. Also, none formed even if the
Pyrex filter was omitted.

Vpc analysis was performed on a Varian Model 90-P gas chromato-
graph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloro-
pthalate on Chromsorb W Regular 60/80, operating at 130°, detector 160°,
filament current 100 ma, helium flow rate 60 cm^3/min.

2,2,2-Trideuteroethanol. The title compound was prepared via
lithium aluminum hydride reduction of tetradeuteroacetic acid. To a
3 neck, 5 liter round bottom flask provided with a stirrer, condenser,
and nitrogen inlet was added 38 g (1 mole) of lithium aluminum hydride.
Cooling was provided by an ice bath while 2 liters of anhydrous ether
was added. Cooling was continued and to this stirred slurry was slowly
added a 250 ml ether solution containing 64 g (1 mole) of tetradeutero-
acetic acid. The mixture was allowed to stand at room temperature for
40 hours with vigorous stirring. Then ice bath cooling was again pro-
vided while 1 liter of 25% sulfuric acid was slowly added. This solu-
tion was distilled through a 2 ft. Vigreux Column. After the ether had
distilled off the ethanol-water azeotrope was collected. Density measure-
ment and nmr analysis indicated that the aqueous solution contained 34.3 g
(.7 mole, 70%) of 2,2,2-trideuteroethanol.

The optimum procedure above was arrived at after extensive experi-
mentations using d_o-acetic acid. Smaller scale runs were equally as
efficient.

<u>2,2,2-Trideuteroethyl Bromide</u>. The title compound was prepared via treatment of 2,2,2-trideuteroethanol with 48% aqueous hydrobromic acid. To 142 ml of 48% aqueous hydrobromic acid were slowly added 50 ml of cold concentrated sulfuric acid, a cold aqueous solution containing 34.2 g (.7 mole) of d_3-ethanol, and another 50 ml of cold concentrated sulfuric acid. Magnetic stirring and ice bath cooling were provided during these additions. The solution was then very gently heated and the d_3-ethyl bromide distilled off as it formed. An efficient condenser using -10° coolant was provided and the distillate collected under ice water. After all the d_3-ethyl bromide distilled over, the distillate was transferred to a separatory funnel and the organic layer isolated and stored.

This complete procedure was repeated 4 times. All the d_3-ethyl bromide was then combined and washed with equivolume portions of concentrated sulfuric acid, water, dilute sodium carbonate, and again with water. After drying over 20 g of anhydrous magnesium sulfate and filtering, there was obtained 294.4 g (2.63 moles, 93.9%) of 2,2,2-trideuteroethyl bromide. The mass spectrum indicated $97.0\pm.1\%$ d_3 content, $1.5\pm.1\%$ d_0, $0.0\pm.1\%$ d_1, and $1.5\pm.1\%$ d_2.

The optimum procedure above was arrived at after extensive experimentations using d_0-ethanol.

<u>Kinetics of the Photolysis of Ethyl Diazoacetate in Ethyl Bromide</u>. See standard procedure for the photolysis of ethyl diazoacetate in alkyl halide solution. The evolved gas was collected over salt water. Data reflecting both the rate of ethyl diazoacetate decomposition and the rate of ethylene formation were desired.

The rate of ethyl diazoacetate decomposition was obtained by allowing the evolved nitrogen and ethylene first to bubble through a carbon tetrachloride solution of bromine which served as a trap for the ethylene. Thus, nitrogen continued on alone and was collected over salt water (Tables 2, 3, and 4). The rate of nitrogen evolution then was used to calculate the rate of decomposition of ethyl diazoacetate. Plots of log millimoles of ethyl diazoacetate vs. time gave a straight line (Figures 5, 6, and 7). Thus, the reaction was first order with respect to ethyl diazoacetate and had a rate constant of $k = 4 \times 10^{-3} \text{ min}^{-1}$.

The course of ethylene formation (Table 5) was followed indirectly by repeating the above procedure but with the trap of bromine in carbon tetrachloride omitted. Thus, both nitrogen and ethylene were collected over salt water. From this data was subtracted that previously obtained when ethylene was trapped out. After converting the volume of ethylene into millimoles a plot (Figure 8) of log millimoles ethylene vs. time gave a straight line with a rate constant of $k = 4 \times 10^{-3} \text{ min}^{-1}$.

Photolysis of Ethyl Diazoacetate in 2,2,2-Trideuteroethyl Bromide. See standard procedure for the photolysis of ethyl diazoacetate in alkyl halide solution. Several runs were made and 2.76±.10 g (16.5±.6 mm, 41.2±1.5%) of ethyl d_1-bromoacetate formed. The mass spectrum of this material showed peaks at 167 and 169 (indicating ethyl d_1-bromoacetate) but nothing at 166 and 168 (indicating no ethyl d_0-bromoacetate).

As ethyl diazoacetate was being decomposed by the UV light the evolved gas was bubbled through a carbon tetrachloride solution of bromine. Thus, the other elimination product, d_2-ethylene, was trapped as 1,2-dibromoethane. The mass spectrum of this material indicated 94.5% d_2 content, 3.5% d_0, 2.1% d_1 and 0.0% d_3.

Table 2. Nitrogen evolution during the photolysis of ethyl diazoacetate

in d_0-EtBr at 10°

V_∞ = Volume of N_2 at infinity, 1020 cm^3

V_t = Volume of N_2 at any time

C_o = initial amount of ethyl diazoacetate, 40 millimoles

Time hr, min	Volume N_2 cm^3	N_2CHCO_2Et Millimoles $\dfrac{V_\infty - V_t}{V_\infty}(C_o)$	log N_2CHCO_2Et Millimoles
0'0"	0	40.0	1.60
0'15"	50	38.1	1.58
0'28"	100	36.1	1.56
0'42"	150	34.1	1.53
0'57"	200	32.2	1.51
1'14"	250	30.3	1.48
1'33"	300	28.2	1.45
1'53"	350	26.3	1.42
2'14"	400	24.3	1.39
2'36"	450	22.4	1.35
2'57"	500	20.4	1.31
3'22"	550	18.5	1.27
3'42"	600	16.5	1.22
4'17"	650	14.5	1.16
4'47"	700	12.6	1.10
5'20"	750	10.6	1.03
6'01"	800	8.6	0.94
6'44"	850	6.7	0.83
8'26"	900	4.0	0.60
9'11"	950	2.7	0.43
22'0"	1020	0.0	

Table 3. Nitrogen evolution during the photolysis of ethyl diazoacetate

in d_o-EtBr at 10°

V_{∞} = Volume of N_2 at infinity, 1010 cm^3

V_t = Volume of N_2 at any time

C_o = initial amount of ethyl diazoacetate, 40 millimoles

Time hr, min	Volume N_2 cm^3	N_2CHCO_2Et Millimoles $\dfrac{V_{\infty} - V_t}{V_{\infty}}(C_o)$	log N_2CHCO_2Et Millimoles
0'0"	0	40.0	1.60
0'15"	50	38.0	1.58
0'32"	100	36.1	1.56
0'46"	150	34.1	1.53
1'03"	200	32.1	1.51
1'24"	250	30.1	1.48
1'47"	300	28.1	1.45
2'13"	350	26.1	1.42
2'39"	400	24.2	1.38
3'09"	450	22.2	1.35
3'33"	500	20.2	1.31
4'04"	550	18.2	1.26
4'39"	600	16.3	1.21
5'21"	650	14.3	1.15
5'57"	700	12.3	1.09
6'36"	750	10.6	1.01
22'0"	1010	0.0	

Table 4. Nitrogen evolution during the photolysis of ethyl diazoacetate in d_o-EtBr at 10°

V_∞ = Volume of N_2 at infinity, 970 cm^3

V_t = Volume of N_2 at any time

C_o = initial amount of ethyl diazoacetate, 40 millimoles

Time hr, min	Volume N_2 cm^3	N_2CHCO_2Et Millimoles $\dfrac{V_\infty - V_t}{V_\infty} \cdot (C_o)$	log N_2CHCO_2Et Millimoles
0'0"	0	40.0	1.60
0'10"	50	38.0	1.58
0'24"	100	35.9	1.56
0'39"	150	33.8	1.53
0'56"	200	31.8	1.50
1'14"	250	29.7	1.47
1'36"	300	27.6	1.44
1'57"	350	25.6	1.41
2'22"	400	23.5	1.37
2'46"	450	21.4	1.33
3'12"	500	19.4	1.29
3'37"	550	17.3	1.24
4'06"	600	15.3	1.18
4'38"	650	13.2	1.12
5'17"	700	11.1	1.05
5'52"	750	9.1	0.96
22'0"	970	0.0	

Table 5. Ethylene formation during the photolysis of ethyl diazoacetate

in d_0-EtBr at 10°

V_∞ = Volume of ethylene at infinity, 373 cm^3

V_t = Volume of ethylene at any time

C_∞ = Total amount of ethylene, 16.5 millimoles

Time hr, min	Volume Ethylene cm^3	Ethylene Millimoles $\frac{V_t}{V_\infty}(C_\infty)$	log Ethylene Millimoles
0'0"	0	0.0	
3'0"	97	4.3	.63
3'30"	111	4.9	.69
4'0"	118	5.2	.72
4'30"	134	5.9	.77
5'0"	140	6.2	.79
5'30"	194	8.6	.93
6'0"	209	9.3	.97
22'0"	373	16.5	

d_2-Ethylene was also collected along with nitrogen in a gas bulb.

The mass spectrum indicated $90\pm1\%$ d_2 content, $2\pm1\%$ d_o, $8\pm1\%$ d_1 and 0.0% d_3.

Vpc analysis was performed on a Varian Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 10% dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 119°, detector 157°, filament current 100 ma, helium flow rate 600 cm^3/min. The internal standard used was ethyl β-bromobutyrate. The following correlation between area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.03 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Kinetics of the Photolysis of Ethyl Diazoacetate in 2,2,2-Trideuteroethyl Bromide. The kinetic procedure previously described for the reaction with d_o-ethyl bromide was used. The rate constant found for the rate of ethyl diazoacetate decomposition was $k = 4 \times 10^{-3}$ min^{-1} (Figures 9, 10 and 11, Tables 6, 7, and 8) and that for d_2-ethylene formation also $k = 4 \times 10^{-3}$ min^{-1} (Figure 12, Table 9).

Competition Experiment: Photolysis of Ethyl Diazoacetate in d_o-Ethyl Bromide Plus d_3-Ethyl Bromide. See standard procedure for the photolysis of ethyl diazoacetate in alkyl halide solution. The alkyl halide consisted of a 50/50 mixture of d_o-ethyl bromide and d_3-ethyl bromide (2,2,2-trideuteroethyl bromide).

The ethyl bromoacetate was examined for d_o and d_1 content. The mass spectrum indicated $d_o/d_1 = 1.02\pm.10$ which reflected the relative rate constants $k_H/k_D = 1.02\pm.10$.

Evolved ethylene was collected along with nitrogen in a gas bulb and examined for d_o and d_2 content. The mass spectrum indicated $d_o/d_2 = .99\pm.04$ which reflected the relative rate constants $k_H/k_D = .99\pm.04$.

Table 6. Nitrogen evolution during the photolysis of ethyl diazoacetate in d_3-EtBr at 10°

V_∞ = Volume of N_2 at infinity, $1010\ cm^3$

V_t = Volume of N_2 at any time

C_o = initial amount of ethyl diazoacetate, 40 millimoles

Time hr, min	Volume N_2 cm^3	N_2CHCO_2Et Millimoles $\dfrac{V_\infty - V_t}{V_\infty}(C_o)$	log N_2CHCO_2Et Millimoles
0'0"	0	40.0	1.60
0'11"	50	38.0	1.58
0'27"	100	36.1	1.56
0'44"	150	34.1	1.53
1'01"	200	32.1	1.51
1'20"	250	30.1	1.48
1'38"	300	28.1	1.45
2'01"	350	26.1	1.42
2'25"	400	24.2	1.38
2'54"	450	22.2	1.35
3'22"	500	20.2	1.31
3'51"	550	18.2	1.26
4'22"	600	16.2	1.21
5'01"	650	14.2	1.15
5'44"	700	12.2	1.09
6'27"	750	10.3	1.01
7'13"	800	8.3	0.92
22'0"	1010	0.0	

Table 7. Nitrogen evolution during the photolysis of ethyl diazoacetate in d_3-EtBr at 10°

V_∞ = Volume of N_2 at infinity, 970 cm^3

V_t = Volume of N_2 at any time

C_o = initial amount of ethyl diazoacetate, 40 millimoles

Time hr, min	Volume N_2 cm^3	N_2CHCO_2Et Millimoles $\dfrac{V_\infty - V_t}{V_\infty}(C_o)$	log N_2CHCO_2Et Millimoles
0'0"	0	40.0	1.60
0'18"	50	38.0	1.58
0'34"	100	35.9	1.56
0'44"	150	33.8	1.53
1'07"	200	31.8	1.50
1'26"	250	29.7	1.47
1'46"	300	27.6	1.44
2'05"	350	25.6	1.41
2'25"	400	23.5	1.37
2'49"	450	21.4	1.33
3'12"	500	19.4	1.29
3'41"	550	17.3	1.24
4'10"	600	15.3	1.18
4'40"	650	13.2	1.12
5'09"	700	11.1	1.05
5'57"	750	9.1	0.96
6'40"	800	7.0	0.05
22'0"	970	0.0	

Table 8. Nitrogen evolution during the photolysis of ethyl diazoacetate

in d_3-EtBr at 10°

V_∞ = Volume of N_2 at infinity, 1010 cm^3

V_t = Volume of N_2 at any time

C_o = initial amount of ethyl diazoacetate, 40 millimoles

Time hr, min	Volume N_2 cm^3	N_2CHCO_2Et Millimoles $\dfrac{V_\infty - V_t}{V_\infty}(C_o)$	log N_2CHCO_2Et Millimoles
0'0"	0	40.0	1.60
0'14"	50	38.0	1.58
0'29"	100	36.1	1.56
0'47"	150	34.1	1.53
1'03"	200	32.1	1.51
1'22"	250	30.1	1.48
1'42"	300	28.1	1.45
2'02"	350	26.1	1.42
2'27"	400	24.2	1.38
2'52"	450	22.2	1.35
3'17"	500	20.2	1.31
3'47"	550	18.2	1.26
4'12"	600	16.2	1.21
4'47"	650	14.2	1.15
5'22"	700	12.2	1.09
6'17"	750	10.3	1.01
6'57"	800	8.3	0.92
22'0"	1010	0.0	

Table 9. Ethylene formation during the photolysis of ethyl diazoacetate in d_3-EtBr at 10°

V_∞ = Volume of ethylene at infinity, 360 cm^3

V_t = Volume of ethylene at any time

C_∞ = Total amount of ethylene, 16.5 millimoles

Time hr, min	Volume Ethylene cm^3	Ethylene Millimoles $\frac{V_t}{V_\infty}(C_\infty)$	log Ethylene Millimoles
0'0"	0	0.0	
3'0"	95	4.2	.63
3'30"	118	5.4	.73
4'0"	134	6.2	.79
4'30"	157	7.2	.86
5'0"	175	8.0	.91
5'30"	198	9.1	.96
6'0"	214	10.0	1.0
22'0"	360	16.5	

The mass spectrometric data above was obtained via 5 separate reaction runs made under identical conditions.

Light Bulb Photolysis of Ethyl Diazoacetate in Ethyl Bromide. A 100 ml (.40 molar) solution of ethyl diazoacetate (40 mm) in ethyl bromide was prepared. This solution was placed in a Pyrex vessel and photolyzed using an ordinary 1500 watt light bulb. The light bulb was enclosed in metal housing which served to focus the light. Tap water coolant maintained the temperature at $25\pm2^\circ$. After 19 days the reaction was complete and 2.79 g (16.7 mm, 41.7%) of ethyl bromoacetate formed. Other peaks present to the extent of ca. 5% were presumably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 142°, detector 169°, filament current 100 ma, helium flow rate 600 cm^3/min. The internal standard used was ethyl β-bromobutyrate. The following correlation between area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.16 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Sunlamp Photolysis of Ethyl Diazoacetate in Ethyl Bromide. A 15 ml (.80 molar) solution of ethyl diazoacetate (12 mm) in ethyl bromide was placed in a Pyrex vessel and photolyzed using a 275 watt General Electric Sunlamp. Cooling was provided by tap water so that the reaction temperature maintained was $25\pm2^\circ$. After 34 hours the reaction was complete and .857 g (5.13 mm, 42.7%) of ethyl bromoacetate formed. Other peaks present to the extent of ca. 5% were presumably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chroma-
tograph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetra-
chloropthalate on Chromsorb W Regular 60/80, operating at 140°, de-
tector 168°, filament current 100 ma, helium flow rate 600 cm^{3}/min.
The internal standard used was ethyl β-bromobutyrate. The following
correlation between area and weight ratios was found employing a stan-
dard solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.12 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Photolysis of Ethyl Diazoacetate in Benzyl Chloride. See standard
procedure for the photolysis of ethyl diazoacetate in alkyl halide solution.
No ethyl chloroacetate formed.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas
chromatograph using a 20' x 3/8" glass column packed with 10% Dibutyl
Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 130°, detec-
tor 160°, filament current 100 ma, helium flow rate 100 cm^{3}/min. Analysis
was also performed on a Varian Aerograph Model A-700 gc using a 10' x 3/8"
glass column packed with 10% Vcon Polar 2000 on Chromsorb W Regular 60/80,
operating at 130°, detector 160°, filament current 100 ma, helium flow
rate 60 cm^{3}/min.

Photolysis of Ethyl Diazoacetate in Ethyl Bromide. The standard
procedure for the photolysis of ethyl diazoacetate in alkyl halide solu-
tion was used except the time and concentration were doubled (50 ml of
1.60 molar ethyl diazoacetate, 80 mm). There was formed 4.06 g (24.3 mm,
30.4%) of ethyl bromoacetate. Other peaks present to the extent of ca.
5% were presumably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chroma-
tograph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetra-
chloropthalate on Chromsorb W Regular 60/80, operating at 142°, detector
173°, filament current 100 ma, helium flow rate 600 cm^3/min. The in-
ternal standard used was ethyl β-bromobutyrate. The following correla-
tion between area and weight ratios was found employing a standard solu-
tion.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.12 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Photolysis of Ethyl Diazoacetate in Ethyl Bromide. The standard
procedure for the photolysis of ethyl diazoacetate in alkyl halide solu-
tion was used except the Pyrex filter was omitted. There was formed
2.46 g (14.7 mm, 36.8%) of ethyl bromoacetate. Other peaks present to
the extent of ca. 5% were presumably the insertion products.

Vpc analysis was performed on a Varian Model 90-P gas chromato-
graph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloro-
pthalate on Chromsorb W Regular 60/80, operating at 143°, detector 175°,
filament current 100 ma, helium flow rate 120 cm^3/min. The internal stan-
dard used was ethyl β-bromobutyrate. The following correlation between
area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.17 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Photolysis of Ethyl Bromoacetate in Ethyl Bromide. The standard
procedure for the photolysis of ethyl diazoacetate in alkyl halide solution
was used except that no ethyl diazoacetate was used, only ethyl bromide
and 3.0 g (18 mm) of ethyl bromoacetate. No decrease in the amount of ethyl
bromoacetate occurred.

This experiment was repeated exactly except the Pyrex filter was omitted. Again, no decrease in the amount of ethyl bromoacetate occurred.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 142°, detector 173°, filament current 100 ma, helium flow rate 600 cm^3/min. The internal standard used was ethyl β-bromobutyrate. The following correlation between area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.15 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Photolysis of Ethyl Diazoacetate in Ethyl Bromide. The standard procedure for the photolysis of ethyl diazoacetate in alkyl halide solution was used except the concentration was decreased (50 ml of .01596 molar ethyl diazoacetate, .798 mm). There was formed 68.7 mg (.412 mm, 51.6%) of ethyl bromoacetate. Other peaks present to the extent of ca. 5% were presumably the insertion products.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 142°, detector 174°, filament current 100 ma, helium flow rate 600 cm^3/min. The internal standard used was ethyl β-bromobutyrate. The following correlation between area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.14 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Photolysis, of Ethyl Diazoacetate in Ethyl Bromide—Benzene Solu-

tion. The standard procedure for the photolysis of ethyl diazoacetate

in alkyl halide solution was used except benzene was present. Thus, the

solution consisted of 25 ml of 1.6 molar ethyl diazoacetate (40 mm) plus

25 ml of benzene. There was formed 1.48 g (8.86 mm, 22.2%) of ethyl

bromoacetate. An unidentified large vpc peak was observed which presum-

ably was due to ethyl diazoacetate reaction with benzene.

This experiment was repeated exactly except the Pyrex filter was

omitted. There was formed .867 g (5.2 mm, 13.0%) of ethyl bromoacetate.

The unidentified peak mentioned above was absent.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas

chromatograph using a 20' x 3/8" glass column packed with 10% Dibutyl

Tetrachloropthalate on Chromsprb W Regular 60/80, operating at 148°, de-

tector 173°, filament current 100 ma, helium flow rate 180 cm^3/min. The

internal standard used was ethyl β-bromobutyrate. The following corre-

lation between area and weight ratios was found employing a standard

solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.20 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Photolysis of Ethyl Diazoacetate in Ethyl Bromide—Cyclohexane

Solution. The standard procedure for the photolysis of ethyl diazoacetate

in alkyl halide solution was used except cyclohexane was present. Thus,

the solution consisted of 25 ml of 1.6 molar ethyl diazoacetate (40 mm)

plus 25 ml of cyclohexane. There was formed 1.64 g (9.81 mm, 24.5%) of

ethyl bromoacetate.

Also formed was ethyl cyclohexylacetate (via ethyl diazoacetate

reaction with cyclohexane) as determined by collection and comparison with an authentic sample.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 143°, detector 170°, filament current 100 ma, helium flow rate 120 cm^3/min. The internal standard used was ethyl β-bromobutyrate. The following correlation between area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.18 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Photolysis of Ethyl Diazoacetate in Ethyl Bromide—Acetone Solution. The standard procedure for the photolysis of ethyl diazoacetate in alkyl halide solution was used except acetone was present. Thus, the solution consisted of 25 ml of 1.6 molar ethyl diazoacetate (40 mm) plus 25 ml of acetone. There was formed 1.472 g (8.8 mm, 22.1%) of ethyl bromoacetate.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 143°, detector 170°, filament current 100 ma, helium flow rate 120 cm^3/min. The internal standard used was ethyl β-bromobutyrate. The following correlation between area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.20 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Photolysis of Ethyl Diazoacetate in Ethyl Bromide—Acetonitrile

Solution. The standard procedure for the photolysis of ethyl diazo-

acetate in alkyl halide solution was used except acetonitrile was

present, Thus, the solution consisted of 25 ml of 1.6 molar ethyl dia-

zoacetate (40 mm) plus 25 ml of acetonitrile. There was formed .6 g

(3.59 mm. 9.0%) of ethyl bromoacetate.

Vpc analysis was performed on a Varian Aerograph Model 90-P

gas chromatograph using a 20' x 3/8" glass column packed with 10% Dibutyl

Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 148°, de-

tector 173°, filament current 100 ma, helium flow rate 180 cm^3/min. The

internal standard used was ethyl β-bromobutyrate. The following corre-

lation between area and weight ratios was found employing a standard

solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.20 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Low Pressure Lamp Photolysis of Ethyl Diazoacetate in Ethyl Bromide.

A 25 ml (1.6 molar) solution of ethyl diazoacetate (40 mm) in ethyl bro-

mide was prepared. Into this solution was directly immersed a low pressure

UV immersion lamp (Ultraviolet Products, Inc., PCQ Model No. SCT 4, .9 amps).

The photolysis vessel was immersed in an ice-water bath which allowed the

reaction temperature to remain at 20 ± 5°. After 96 hours the reaction was

complete and 1.65 g (9.87 mm, 24.7%) of ethyl bromoacetate formed. Other

peaks present to the extent of ca. 5% were presumably the insertion pro-

ducts.

This reaction was repeated exactly except at higher dilution, 25 ml

of .80 molar ethyl diazoacetate, and .968 g (5.8 mm, 29%) of ethyl bromo-

acetate formed.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 10' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 130°, detector 172°, filament current 100 ma, helium flow rate 150 cm^3/min. The internal standard used was ethyl β-bromobutyrate. The following correlation between area and weight ratios was found employing a standard solution.

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl β-bromobutyrate}} \times 1.16 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl β-bromobutyrate}}$$

Copper Catalyzed Reaction of Ethyl Diazoacetate in Ethyl Bromide.

A 50 ml solution of .80 molar ethyl diazoacetate (40 mm) was prepared. A gram of copper powder was added and the solution was refluxed with stirring for 51 hours in the dark The solution was filtered and excess ethyl bromide removed. Found were .59 g (3.43 mm, 17.2%) of ethyl maleate and .226 g (1.32 mm, 6.6%) of ethyl fumarate but no trace of either ethyl bromoacetate or insertion products.

Vpc analysis was performed on a Varian Aerograph Model A-700 gas chromatograph using a 10' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 150°, detector 219°, filament current 100 ma, helium flow rate 60 cm^3/min. A dilute standard solution was prepared and 10 microliter quantities injected to obtain a correlation of 381 mm^2/mg for ethyl maleate and 360 mm^2/mg for ethyl fumarate. The reaction solution concentrate was injected and correlated with the information above to obtain the quantities present.

Addition of Deuterium Bromide to Indene. To a tall 500 ml gas washing bottle fitted with a drying tube was added 15 g (124 mm) of indene and 300 ml of pentane.[179] The reaction vessel was immersed in a Dry Ice-acetone bath and light excluded. A stopcock was opened and 55 g (670 mm) of previously prepared deuterium bromide was allowed to distill into the reaction mixture over a period of 3 hours. The reaction mixture was allowed to stand 13 hours more. Solvent and excess deuterium bromide were removed via a rotary evaporator. The residue was diluted with 150 ml of pentane, filtered to remove some unidentified solid, and dried over 20 g of anhydrous magnesium sulfate for 10 minutes. The solution was filtered, pentane removed via a rotary evaporator, and a liquid residue of 1-bromo-2-deuteroindane obtained. Analysis, as described below, indicated this to consist of 80% cis and 20% trans adduct.

N.m.r. Analysis of Cis to Trans Ratio. The 1-bromo-2d-indane was analyzed by nuclear magnetic resonance (Figure 13). This involved measurement of the splitting of the CHBr proton signal, δ 5.27, due to interaction with the adjacent CHD proton. The nmr spectrum immediately showed the predominance of the cis adduct (0° dihedral bond angle between the C-H bonds, therefore, an expected large coupling constant of ca. 6-9 cps). The amount of trans adduct (120° dihedral angle between the C-H bonds, therefore, an expected small coupling constant of ca. 2-3 cps) was small. The per cent cis and trans adduct was estimated by peak height measurements to be 80±5% cis and 20±5% trans.[179]

Photolysis and Thermolysis of Ethyl Diazoacetate in 1-Bromo-2-deuteroindane. A solution containing 1.0 g (8.7 mm) of ethyl diazoacetate and 6.9 g (35 mm) of 1-bromo-2d-indane (80% cis, 20% trans) was

placed in a Pyrex vessel and photolyzed using a 275 watt General Electric Sunlamp. Cooling was provided by tap water so that the reaction temperature maintained was $25\pm2^{\circ}$. After 48 hours the reaction was complete. The ethyl bromoacetate product was collected via vpc with plans to determine the deuterium content from the mass spectrum.

A solution containing 1.0 g (8.7 mm) of ethyl diazoacetate and 5.8 g (29 mm) of 1-bromo-2d-indane (80% cis, 20% trans) was heated on a steam bath until nitrogen evolution ceased (12 minutes). A sample of ethyl bromoacetate was again collected via vpc.

At this point it was discovered that the 80% cis, 20% trans 1-bromo-2d-indane equilibrated readily to a 50/50 mixture (Figure 14). At room temperature this occurred within 24 hours. This previously unrecognized fact obviously negated results from the experiments described above.

Numerous attempts (employing extensive variations) then were made to carry out the photolysis at reduced temperatures (to retard the isomerication toward 50/50 composition). These considerable efforts were thwarted, the basic problem being that ethyl diazoacetate "froze" out of solution.

With much dismay, attempts to utilize this substrate to determine the reaction stereochemistry were therefore finally abandoned.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 15% SE 30 on Chromsorb W Regular 60/80, operating at 135°, detector 159°, filament current 100 ma, helium flow rate 100 cm^3/min.

Photolysis of Ethyl Diazoacetate in Iodobenzene. See standard

procedure for the photolysis of ethyl diazoacetate in alkyl halide

solution. No ethyl iodoacetate was formed.

Vpc analysis was performed on a Varian Aerograph Model 90-P

gas chromatograph using a 20' x 3/8" glass column packed with 15% SE 30

on Chromsorb W Regular 60/80, operating at 138°, detector 172°, filament

current 100 ma, helium flow rate 200 cm^3/min.

Photolysis of Ethyl α-Bromobutyrate in Benzene. A 50 ml solution

containing 7.80 g (40 mm) of ethyl α-bromobutyrate in benzene was pre-

pared. This solution was photolyzed employing the standard procedure

for the photolysis of ethyl diazoacetate in alkyl halide solution. No

ethyl bromoacetate formed.

This experiment was repeated but with the Pyrex filter omitted.

Again no ethyl bromoacetate formed.

Vpc analysis was performed on a Varian Aerograph Model 90-P

gas chromatograph using a 20' x 3/8" glass column packed with 15% SE 30

on Chromsorb W Regular 60/80, operating at 138°, detector 172°, filament

current 100 ma, helium flow rate 200 cm^3/min.

Photolysis of Ethyl Diazoacetate in Ethyl Bromide—Ethyl α-Bromo-

butyrate Solution. The standard procedure for the photolysis of ethyl

diazoacetate in alkyl halide solution was employed. The solution con-

sisted of the usual 50 ml of .80 molar ethyl diazoacetate (40 mm) in

ethyl bromide and in addition 2.0 g of ethyl α-bromobutyrate was added.

There was formed 2.5 g (15.0 mm, 37.5%) of ethyl bromoacetate. Further-

more, the added amount of ethyl α-bromobutyrate was still present.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas

chromatograph using a 20' x 3/8" glass column packed with 15% SE 30 on

Chromsorb W Regular 60/80, operating at 138°, detector 172°, filament current 100 ma, helium flow rate 200 cm³/min. The internal standard used was ethyl β-bromobutyrate. By employing a standard solution it was found that within experimental error area per cent equalled weight per cent for these components.

Photolysis of Ethyl Diazoacetate in 1-Fluorohexane. A solution containing 1.0 g (8.7 mm) of ethyl diazoacetate and 4 ml of 1-fluorohexane was placed in a Pyrex vessel and photolyzed using a 275 watt General Electric Sunlamp. Cooling was provided by tap water so that the reaction temperature maintained was 25±2°. After 96 hours the reaction was complete. No ethyl fluoroacetate formed.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 15% SE 30 on Chromsorb W Regular 60/80, operating at 138°, detector 172°, filament current 100 ma, helium flow rate 200 cm³/min. Analysis was also made using a 4' x 1/8" metal column packed with 10% Carbowax 20M on Anachrom ABS 90/100, operating at 72°, detector 190°, filament current 100 ma, helium flow rate 60 cm³/min.

Competition Experiment: Photolysis of Ethyl Diazoacetate in a Mixture of 2-Bromopropane, 2-Chloropropane, and 2-Iodopropane. See standard procedure for the photolysis of ethyl diazoacetate in alkyl halide solution. The alkyl halide consisted of an equimolar mixture of 2-bromopropane, 2-chloropropane, and 2-iodopropane. Three runs were made and ethyl chloroacetate, ethyl bromoacetate, and ethyl iodoacetate formed. Relative molar amounts present (a reflection of the relative reaction rates) were ethyl chloroacetate 1.00, ethyl bromoacetate 1.47±.01, and ethyl iodoacetate 2.20±.17.

The relative reaction rates plotted against the C-halogen bond energies (Figure 2) formed a straight line.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 15% SE 30 on Chromsorb W Regular 60/80, operating at 138°, detector 172°, filament current 100 ma, helium flow rate 200 cm³/min. By employing a standard solution it was found that within experimental error area per cent equalled millimole per cent for these components.

Photosensitized Photolysis of Ethyl Diazoacetate in Ethyl Bromide. The procedure for the photolysis of ethyl diazoacetate in alkyl halide solution was used except 6.8 g (40 mm) of benzophenone was also present to serve as a photosensitizing agent. There was formed 1.164 g (7.0 mm, 17.5%) of ethyl bromoacetate.

This experiment was repeated with an additional filter consisting of an aqueous solution of nickel sulfate (.18 molar) and cobalt sulfate (.18 molar). This filter solution circulated through the immersion well and thus served also as coolant to dissipate heat generated by the lamp. There was formed 1.11 g (6.65 mm, 16.6%) of ethyl bromoacetate.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 10' x 3/8" column packed with 10% Dibutyl Tetrachloropthalate Chromsorb W Regular 60/80, operating at 132°, detector 160°, filament current 100 ma, helium flow rate 200 cm³/min. The internal standard used was ethyl α-bromobutyrate. By employing a standard solution it was found that within experimental error area per cent equalled weight per cent.

Photolysis of Ethyl Diazoacetate in Neopentyl Bromide. See standard procedure for the photolysis of ethyl diazoacetate in alkyl halide solution. Three runs were made and the two product peaks were identified as ethyl α-bromo-γ, γ-dimethylvalerate (the C-Br insertion product) and ethyl δ-bromo-γ, γ-dimethylvalerate (the C-H insertion product) in a relative millimole ratio of 4.3±.3 to 1. Thus, the C-Br insertion product greatly predominated despite the fact that 9 γ C-H bonds competed with the C-Br bond for the carbethoxycarbene. Taking the number of bonds into account, the relative reactivity of the C-Br and a γ C-H bond in neopentyl bromide was readily computed and found to be 38.7±2.7 to 1.

No ethyl bromoacetate could be detected nor any products resulting from rearrangement of the neopentyl skeleton.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 10' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 110°, detector 170°, filament current 100 ma, helium flow rate 300 cm^3/min. For these isomers it was assumed that area per cent equalled weight per cent.

Photolysis of Ethyl Diazoacetate in Ethyl Bromide. A 250 ml (.35 molar) solution of ethyl diazoacetate (87.6 mm) in ethyl bromide was prepared. This solution was photolyzed for 48 hours with a medium pressure Hanovia UV Lamp at $10\pm1^{\circ}$ in a manner analogous to that previously described in the standard procedure for the photolysis of ethyl diazoacetate in alkyl halide solution. There was formed 5.52 g (33.1 mm, 37.8%) of ethyl bromoacetate.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 10' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 120°, detector 170°, filament current 100 ma, helium flow rate 150 cm^3/min. The internal standard used was ethyl α-bromobutyrate. By employing a standard solution it was found that within experimental error area per cent equalled weight per cent.

Photolysis of Ethyl Diazoacetate in Ethyl Bromide. For 24 hours nitrogen was bubbled through a fritted disc into ethyl bromide. This ethyl bromide was then used to prepare a .35 molar ethyl diazo-acetate solution and then photolyzed as described above except that nitrogen continuously bubbled through during the entire photolysis. There was formed 5.48 g (32.8 mm, 37.5%) of ethyl bromoacetate.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 10' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 120°, detector 170°, filament current 100 ma, helium flow rate 150 cm^3/min. The internal standard used was ethyl α-bromobutyrate. By employing a standard solution it was found that within experimental error area per cent equalled weight per cent.

Photolysis of Ethyl Diazoacetate in Ethyl Bromide. For 24 hours oxygen was bubbled through a fritted disc into ethyl bromide. This ethyl bromide was then used to prepare a .35 molar ethyl diazo-acetate solution and then photolyzed as described above except that oxygen continuously bubbled through during the entire photolysis. There was formed 4.68 g (28.0 mm, 32.0%) of ethyl bromoacetate.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas

chromatograph using a 10 ' x 3/8" glass column packed with 10% Dibutyl

Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 120°,

detector 170°, filament current 100 ma, helium flow rate 150 cm^3/min.

The internal standard used was ethyl α-bromobutyrate. By employing

a standard solution it was found that within experimental error area

per cent equalled weight per cent.

Photolysis of Ethyl Diazoacetate in Cyclohexane. A 250 ml (.35

molar) solution of ethyl diazoacetate (87.6 mm) in cyclohexane was pre-

pared. This solution was photolyzed for 48 hours with a medium pressure

Hanovia UV Lamp at $10\pm1^\circ$ in a manner analogous to that previously des-

cribed in the standard procedure for the photolysis of ethyl diazoacetate

in alkyl hlaide solution. There was formed 5.71 g (33.6 mm, 38.3%) of

ethyl cyclohexylacetate.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas

chromatograph using a 10' x 3/8" metal column packed with 10% Polyester

Succinate on Chromsorb W Regular 60/80, operating at 184°, detector 200°,

filament current 100 ma, helium flow rate 120 cm^3/min. The internal

standard used was ethyl phenylacetate. By employing a standard solution

it was found that area per cent equalled weight per cent.

Photolysis- of Ethyl Diazoacetate in Cyclohexane. For 24 hours

nitrogen was bubbled through a fritted disc into cyclohexane. This

cyclohexane was then used to prepare a .35 molar ethyl diazoacetate

solution and then photolyzed as described above except that nitrogen con-

tinuously bubbled through during the entire photolysis. There was formed

5.77 g (33.9 mm, 38.7%) of ethyl cyclohexylacetate.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 10' x 3/8" metal column packed with 10% Polyester Succinate on Chromsorb W Regular 60/80, operating at 184°, detector 200°, filament current 100 ma, helium flow rate 120 cm^3/min. The internal standard used was ethyl phenylacetate. By employing a standard solution it was found that area per cent equalled weight per cent.

Photolysis of Ethyl Diazoacetate in Cyclohexane. For 24 hours oxygen was bubbled through a fritted disc into cyclohexane. This cyclohexane was then used to prepare a .35 molar ethyl diazoacetate solution and then photolyzed as described above except that oxygen continuously bubbled through during the entire photolysis. There was formed 5.28 g (31.1 mm, 35.5%) of ethyl cyclohexylacetate.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph uisng a 10' x 3/8" metal column packed with 10% Polyester Succinate on Chromsorb W Regular 60/80, operating at 184°, detector 200°, filament current 100 ma, helium flow rate 120 cm^3/min. The internal standard used was ethyl phenylacetate. By employing a standard solution it was found that area per cent equalled weight per cent.

Competition Experiment: Photolysis of Ethyl Diazoacetate in Ethyl Bromide—Cyclohexane Solution. A 250 ml (.35 molar) solution of ethyl diazoacetate (87.6 mm) in ethyl bromide—cyclohexane was prepared. The ethyl bromide—cyclohexane consisted of equal volumes of each which computes on a relative millimole basis to be 1.41 mm ethyl bromide to 1 mm of cyclohexane. This solution was photolyzed for 48 hours with a medium pressure Hanovia UV Lamp at 10±1° in a manner analogous to that previously described in the standard procedure for the photolysis of ethyl diazoacetate

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in alkyl halide solution. Thus, ethyl bromide and cyclohexane competed with one another for the privilege to react with carbethoxycarbene. Two runs were made and there was formed ethyl bromoacetate and ethyl cyclohexylacetate in a relative millimole proportion of 1.87±.13 to 1.0. Taking into consideration the fact that the solution contained 1.41 mm of ethyl bromide per 1 mm of cyclohexane, it is apparent that carbethoxycarbene reaction with ethyl bromide to form ethyl bromoacetate was 1.32±.10 times as fast as carbethoxycarbene reaction with cyclohexane to form ethyl cyclohexylacetate. Of course only one C-Br bond was available in ethyl bromide to compete against 12 C-H bonds in cyclohexane. Thus, one C-Br bond in ethyl bromide proved to be 15.8±1.2 (i.e., 1.32±.1 x 12) times as reactive as one C-H bond in cyclohexane.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas chromatograph using a 10' x 3/8" metal column packed with 10% Polyester Succinate on Chromsorb W Regular 60/80, operating at 150°, detector 180°, filament current 100 ma, helium flow rate 120 cm^3/min. The internal standard used was ethyl phenylacetate. The following correlations between area and weight ratios were found employing a standard solution.

$$\frac{\text{Area of ethyl cyclohexylacetate}}{\text{Area of ethyl phenylacetate}} = \frac{\text{Weight of ethyl cyclohexylacetate}}{\text{Weight of ethyl phenylacetate}}$$

$$\frac{\text{Area of ethyl bromoacetate}}{\text{Area of ethyl phenylacetate}} \text{ x } 2.3 = \frac{\text{Weight of ethyl bromoacetate}}{\text{Weight of ethyl phenylacetate}}$$

Photolysis of Ethyl Bromide Containing Benzophenone. A 50 ml solution of ethyl bromide containing 5 g (27.5 mm) of benzophenone was prepared. This solution was photolyzed employing a Pyrex filter for 22 hours in a manner analogous to the standard procedure for the photolysis of ethyl diazoacetate in alkyl halide solution. During the photolysis no gas evolved, indicating no ethylene or hydrogen bromide formation.

Furthermore, the photolyzed solution was not acidic to moist litmus.

When 1 g of ethyl diazoacetate was added to the solution no gas was

evolved. After dilute hydrogen chloride was added to destroy ethyl

diazoacetate, the aqueous and organic layers were separated. The

aqueous layer was extracted with ethyl bromide and the organic solu-

tions combined and dried over anhydrous magnesium sulfate. Vpc analy-

sis revealed the presence of ethyl chloroacetate but no ethyl bromo-

acetate.

Photolysis of Ethyl Diazoacetate in a Hexafluorobenzene Solution

Containing 2-Bromo-3d-bicyclo-[2.2.2]-octane. A solution containing

1 g of 2-bromo-3d-bicyclo-[2.2.2]-octane (80% cis, 20% trans), 1 g of

ethyl diazoacetate, and 4 ml of hexafluorobenzene was photolyzed in

a Pyrex vessel using two 275 watt General Electric Sunlamps. Cooling

was provided by tap water so that the reaction temperature maintained

was $25 \pm 2^\circ$. After 48 hours another gram of ethyl diazoacetate was

added and photolysis continued for an additional 72 hours. The ethyl

bromoacetate and bicyclo-[2.2.2]-octene products were collected via

vpc. Subsequent mass spectrometric analysis revealed that the ethyl

bromoacetate product contained $32.6 \pm 1.0\%$ d_o and $67.4 \pm 1.0\%$ d_1, indi-

cative of $80 \pm 7\%$ cis and $20 \pm 7\%$ trans elimination; whereas, the other

elimination product, bicyclo-[2.2.2]-octene, contained $66.0 \pm 2.7\%$ d_o

and $34.0 \pm 2.7\%$ d_1, indicative of $78 \pm 9\%$ cis and $22 \pm 9\%$ trans elimination.

These figures reflect the results from six independent runs.

Vpc analysis was performed on a Varian Model 90-P gas chromato-

graph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetra-

chloropthalate on Chromsorb W Regular 60/80, operating at 140°, detector

180°, filament current 100 ma, helium flow rate 300 cm^3/min.

Potassium t-Butoxide Reaction with 2-Bromo-3d-bicyclo-$[2.2.2]$-octane.

A solution containing 2 g (17.4 mm) of potassium t-butoxide, 1.74 g (9.15 mm) of 2-bromo-3d-bicyclo-$[2.2.2]$-octane (80% cis, 20% trans), and 30 ml of t-butyl alcohol was refluxed for six days. The solution was dumped into 50 ml of ice water and extracted twice with 25 ml portions of pentane. The combined pentane extracts were extracted 10 times with 20 ml portions of water to remove t-butyl alcohol. After drying over anhydrous magnesium sulfate the pentane solution was filtered and most of the pentane removed by distillation on a steam bath. The bicyclo-$[2.2.2]$-octene was obtained from the concentrate via vpc. Subsequent mass spectrometric analysis revealed that the product contained $35.3 \pm 1.7\%$ d_0 and $64.7 \pm 1.7\%$ d_1, indicative of $24 \pm 7\%$ cis and $76 \pm 7\%$ trans elimination. These figures reflect the results from three independent runs.

Vpc analysis was performed on a Varian Model 90-P gas chromatograph using a 20' x 3/8" glass column packed with 10% Dibutyl Tetrachloropthalate on Chromsorb W Regular 60/80, operating at 140°, detector 180°, filament current 100 ma, helium flow rate 300 cm^3/min.

BIBLIOGRAPHY

1. T. Curtius, Chem. Ber., 16, 754, 2230 (1883).

2. N. E. Searle in Rabjohn, "Organic Syntheses," Collective Volume 4, John Wiley and Sons, Inc., New York, N. Y., 1963, p. 424.

3. A. Angeli, Gass. Chim. Ital., 24, 370 (1894).

4. A. Angeli, Chem. Ber., 37, 2080 (1904).

5. H. v. Pechman and P. Marck, Chem. Ber., 28, 2377 (1895).

6. W. v. E. Doering and C. H. Depuy, J. Am. Chem. Soc., 75, 5955 (1953).

7. A. Schoberg, J. Chem. Soc., 1368, (1951).

8. J. Thiele, Chem. Ber., 44, 3336 (1911).

9. A. Angeli, Attiaccad. Lincei, 20, 625 (1911).

10. S. Ray, J. Ind. Chem. Soc., 12, 780 (1935).

11. K. Clusius and U. Luthi, Helv. Chim. Acta., 40, 445 (1957).

12. C. G. Overberger, J. P. Anselme, and J. G. Lombardino, "Organic Compounds with Nitrogen-Nitrogen Bonds," Ronald Press Co., New York, N. Y., 1966, p. 48.

13. H. Boersch, Monatsh., 65, 331 (1935).

14. J. O. Roberts and M. C. Caserio, "Basic Principles of Organic Chemistry," W. A. Benjamin, Inc., New York, N. Y., 1965, p. 695.

15. I. G. Csizmadia, S. A. Houlden, O. Meresz, and P. Yates, Tetrahedron, 25, 2121 (1969).

16. F. Kaplan and G. K. Meloy, J. Am. Chem. Soc., 88, 950 (1966).

17. R. R. Rando, The Intramolecular Carbene Reaction, Ph.D. Dissertation, Yale University, 36 (1967).

18. J. G. Calvert and J. N. Pitts, Jr., "Photochemistry," John Wiley & Sons, Inc., New York, N. Y., 1966, p. 454.

19. W. Kirmse, "Carbene Chemistry," Academic Press, Inc., New York, N. Y., 1964, p. 95.

20. E. Ciganek, J. Am. Chem. Soc., 88, 1982 (1966).

21. P. S. Skell and R. M. Etter, Proc. Chem. Soc., 443 (1961).

22. R. A. Moss, Chem. and Eng. News, 47, No. 27, 50 (1969).

23. W. Kirmse, ref. 19, p. 95.

24. R. A. Moss, Chem. and Eng. News, 47, No. 25, 60 (1969).

25. P. P. Gaspar and G. S. Hammond in W. Kirmse, ref. 19, p. 270.

26. P. P. Gaspar and G. S. Hammond in W. Kirmse, ref. 19, p. 260.

27. W. Kirmse, ref. 19, pp. 77, 87.

28. W. v. E. Doering and T. Mole, Tetrahedron, 10, 65 (1960).

29. I. A. Dyakonov, M. I. Komendatov, F. Guj-sija, and L. G. Koricev, Zhur. Obshchei Khim., 32, 928 (1962).

30. E. Buchner and J. Geronimus, Chem. Ber., 36, 3782 (1903).

31. S. Akiyoshi and T. Matsuca, J. Am. Chem. Soc., 77, 2476 (1955).

32. H. M. Walborsky and F. M. Hornyak, J. Am. Chem. Soc., 77, 6026 (1955).

33. R. Pettit, Chem. and Ind., 1306 (1956).

34. I. A. Dyakonov, Zhur. Obshchei Khim., 19, 1891 (1949).

35. I. A. Dyakonov and N. A. Lugovtsova, Zhur. Obshchei Khim., 21, 839 (1951).

36. R. Paul and S. Tchelitcheff, Compt. rend., 244, 2806 (1957).

37. M. F. Dull and P. G. Abend, J. Am. Chem. Soc., 81, 2588 (1959).

38. I. A. Dyakonov, Zhur. Obshchei Khim., 20, 2289 (1950).

39. I. A. Dyakonov and O. V. Guseva, Zhur. Obshchei Khim., 22, 1355 (1952).

40. I. E. Dolgij, A. P. Mescerjakov, and G. K. Gajvoronskaja, Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk, 572 (1963).

41. I. A. Dyakonov and N. D. Pirogova, Zhur. Obshchei Khim., 21, 1979 (1951).

42. I. A. Dyakonov and N. B. Vinogradova, Zhur. Obshchei Khim., 22, 1349 (1952).

43. I. A. Dyakonov and V. F. Myznikova, Shornik Statei Obshchei Khim., Akad. Nauk S.S.S.R., 1, 489 (1953).

44. B. Fohlisch, Chem. Ber., 97, 88 (1964).

45. C. v. d. Heide, Chem. Ber., 37, 2101 (1904).

46. S. H. Harper and H. W. B. Reed, J. Chem. Soc., 779 (1955).

47. D. D. Phillips, J. Am. Chem. Soc., 77, 5179 (1955).

48. M. I. Gorjajev and G. A. Tolstikov, Zhur. Obshchei Khim., 32, 310 (1962).

49. F. Korte, K. H. Buchel, and F. F. Wiese, Ann., 664, 114 (1963).

50. R. R. Sauers and P. E. Sonnet, Chem. and Ind., 786 (1963).

51. K. B. Wiberg and J. Bartley, J. Am. Chem. Soc., 82, 6375 (1960).

52. I. A. Dyakonov, T. V. Domareva-Mandelshtam, and V. V. Razin, Zhur. Obshchei Khim., 33, 3437 (1963).

53. J. Warkentin, E. Singleton, and J. F. Edgar, Can. J. Chem., 43, 3456 (1965).

54. R. R. Sauers and P. E. Sonnet, Tetrahedron, 20, 1029 (1964).

55. A. P. Meshcheryakov and I. E. Dolgii, Izvest. Akad. Nauk S.S.S.R., Otdel Khim. Nauk, 1874 (1960).

56. A. P. Meshcheryakov and I. E. Dolgii, Trudy po Khim. i. Khim. Tekhnol., 4, 101 (1961).

57. A. P. Meshcheryakov and I. E. Dolgii, Izvest. Akad. Nauk S.S.S.R., Otdel. Khim. Nauk, 931 (1960).

58. W. M. Jones, J. Am. Chem. Soc., 81, 3776 (1959).

59. I. A. Dyakonov, M. I. Komendantov, K. Fu, and G. L. Korichev, Zhur. Obshchei Khim., 32, 928 (1962).

60. I. A. Dyakonov and T. V. Domareva, Zhur. Obshchei Khim., 25, 1486 (1955).

61. E. Buchner and K. Rehorst, Chem. Ber., 46, 2681 (1913).

62. H. Fischer and H. Medick, Ann., 517, 245 (1935).

63. H. Fischer, Z. physiol. Chem., 234, 97 (1935).

64. H. Fischer and K. Kahr, Ann., 524, 251 (1936).

65. W. Kirmse, ref. 19, p. 99.

66. E. Buchner and T. Curtius, Chem. Ber., 18, 2377 (1885).

67. W. v. E. Doering, et al., J. Am. Chem. Soc., 78, 5448 (1956).

68. W. Kirmse, ref. 19, p. 103.

69. E. Buchner and P. Schulze, Ann., 377, 259 (1910).

70. E. Buchner and K. Schottenhammer, Chem. Ber., 53, 865 (1920).

71. L. I. Smith and P. O. Tawney, J. Am. Chem. Soc., 56, 2167 (1934).

72. L. I. Smith and C. L. Agre, J. Am. Chem. Soc., 60, 648 (1938).

73. G. Juppe and R. Huisgen, Ann., 646, 1 (1961).

74. R. Huisgen and G. Juppe, Tetrahedron, 15, 7 (1961).

75. G. M. Badger, J. W. Cook, and A. R. M. Gibb, J. Chem. Soc., 3456 (1951).

76. N. L. Drake and T. R. Sweeney, J. Org. Chem., 11, 67 (1946).

77. K. Hafner, Angew. Chem., 70, 419 (1958).

78. G. O. Schenck and R. Steinmetz, Angew. Chem., 70, 504 (1958).

79. G. M. Badger, B. J. Christie, H. J. Rodda, and J. M. Pyrke, J. Chem. Soc., 1179 (1958).

80. R. Pettit, Tetrahedron Letters, 23, 11 (1960).

81. G. M. Badger, H. J. Rodda, and J. M. Sassee, J. Chem. Soc., 4777 (1958).

82. W. Treibs and A. Stein, Ann., 572, 165 (1951).

83. R. Huisgen, H. Konig, G. Binsch, and H. J. Sturm, Angew. Chem., 83, 368 (1961).

84. E. Muller, _Chem. Ber._, 47, 3001 (1914).

85. A. Schonberg and E. Frese, _Chem. Ber._, 96, 2420 (1963).

86. F. Arndt, J. Amende, and W. Ender, _Monatsch._, 59, 207 (1932).

87. R. Huisgen, _Angew. Chem._, _International English Edition_ (and numerous later publications), 565 (1963).

88. D. L. Storm and T. A. Spencer, _Tetrahedron Letters_, 20, 1865 (1967).

89. A. Schonberg and N. Latif, _J. Chem. Soc._, 446 (1952).

90. J. Hine, "Divalent Carbon," Ronald Press Co., New York, N. Y., 1964, pp. 16-19.

91. W. Kirmse, ref. 19, p. 21.

92. J. W. Simons and B. S. Rabinovitch, _J. Phys. Chem._, 68, 1322 (1964).

93. H. M. Frey, _Progress in Reaction Kinetics_, 2, 131 (1964).

94. W. B. DeMore and S. W. Benson, _Advances in Photochemistry_, 2, 219 (1964).

95. D. W. Setzer, _J. Am. Chem. Soc._, 87, 2062 (1965).

96. J. D. Collins, Ph.D. Dissertation, U. of Arkansas (1970).

97. F. X. Powell and David R. Lide, Jr., _J. Chem. Phys._, 45, 1067 (1966).

98. J. Hine, ref. 90, p. 19.

99. R. A. Moss, ref. 24, pp. 61-62.

100. J. Hine, ref. 90, p. 44.

101. E. Buchner and T. Curtius, _Chem. Ber._, 18, 2371 (1885).

102. F. Schlotterbeck, _Chem. Ber._, 40, 300 (1907).

103. F. Schlotterbeck, _Chem. Ber._, 42, 2565 (1909).

104. W. v. E. Doering and L. H. Knox, _J. Am. Chem. Soc._, 78, 4947 (1956).

105. D. B. Richardson, M. C. Simmons, and I. Dveretzky, _J. Am. Chem. Soc._, 83, 1934 (1961).

106. G. S. Hammond, _J_. _Am_. _Chem_. _Soc_., _77_, 334 (1955).

107. P. P. Gaspar and G. S. Hammond in W. Kirmse, ref. 19, p. 256.

108. R. R. Sauers and R. J. Kiesel, _J_. _Am_. _Chem_. _Soc_., _89_, 4695 (1967).

109. V. Franzen and J. Kuntze, _Ann_., _627_, 15 (1959).

110. A. W. Johnson, A. Langermann, and J. Murray, _J_. _Chem_. _Soc_., 2136 (1953).

111. C. D. Gutsche and M. Hillman, _J_. _Am_. _Chem_. _Soc_., _76_, 2236 (1954).

112. O. P. Strausz, DoMinh, and H. E. Gunning, _J_. _Am_. _Chem_. _Soc_., _90_, 1660 (1968).

113. D. D. Phillips, _J_. _Am_. _Chem_. _Soc_., _76_, 5385 (1954).

114. W. H. Urry and J. W. Wilt, _J_. _Am_. _Chem_. _Soc_., _76_, 2594 (1954).

115. N. Bilow, _Ph.D_. _Dissertation_, U. of Chicago (1956).

116. I. A. Dyakonov and N. B. Vinogradova, _Zhur_. _Obshchei Khim_., _21_, 851 (1951).

117. I. A. Dyakonov and N. B. Vinogradova, _Zhur_. _Obshchei Khim_., _23_, 66 (1953).

118. T. Curtius, _J_. _prakt_. _Chem_., _38_, 396 (1888).

119. F. Weygaud and H. J. Bestmann, _Chem_. _Ber_., _89_, 1912 (1956).

120. A. Schoenberg and K. Praefcke, _Chem_. _Ber_., _102_, 778 (1967).

121. J. W. Wilt, _Ph.D_. _Dissertation_, U. of Chicago (1954).

122. H. D. Roth,[144] personal communication, has recently obtained some surprising Chemically Induced Dynamic Nuclear Polarization information which supports a mechanism involving a short radical chain mechanism.

123. W. Kirmse, ref. 19, p. 109.

124. A. P. Marchand and N. M. Brockway, unpublished results.

125. I. A. Dyakonov and T. V. Domareva, _Zhur_. _Obshchei Khim_., _29_, 3099 (1959).

126. V. Franzen, _Ann_., _627_, 22 (1958).

127. P. Pino, L. Lavdicci, and L. Centoni, _J_. _Org_. _Chem_., _24_, 1399 (1959).

128. J. Hine, ref. 90, p. 130.

129. J. Hine, ref. 90, p. 132.

130. I. A. Dyakonov and M. I. Komendantov, _Zhur. Obshchei Khim._, _31_, 3881 (1961).

131. R. Breslow, _J. Am. Chem. Soc._, _79_, 5318 (1957).

132. R. Beslow, R. Winter, and M. Battiste, _J. Org. Chem._, _24_, 414 (1959).

133. R. Breslow and D. Chipman, _Chem. and Ind._, 1105 (1960).

134. R. Huisgen, H. J. Sturm and G. Binsch, _Chem. Ber._, _97_, 2864 (1964).

135. A. P. Marchand and N. M. Brockway, personal experience confirms the reference 19 report that no dimer is formed in photolytic reactions.

136. W. Kirmse, ref. 19, p. 106.

137. V. Franzen, _Ann._, _627_, 22 (1959).

138. W. Kirmse, H. Dietrich, and H. W. Bucking, _Tetrahedron Letters_, 1833 (1967).

139. J. A. Kaufman and S. J. Weininger, _Chem. Comm._, 593 (1969).

140. M. Jones and W. Ando, _J. Am. Chem. Soc._, _90_, 2200 (1968).

141. G. O. Schenck and A. Ritter, _Tetrahedron Letters_, 3189 (1968).

142. J. G. Calvert and J. N. Pitts, Jr., ref. 18, p. 523.

143. W. Lwowski, Research Professor, U. of New Mexico, Las Cruces, New Mexico, personal communication.

144. H. D. Roth, Bell Laboratory, Murray Hill, New Jersey, personal communication.

145. J. G. Calvert and J. N. Pitts, Jr., ref. 18, p. 346.

146. J. G. Burr, Professor, U. of Oklahoma, Norman, Oklahoma, personal communication.

147. N. J. Turro, "Molecular Photochemistry," W. A. Benjamin, Inc., 1967, p. 48.

148. J. G. Calvert and J. N. Pitts, Jr., ref. 18, p. 558.

149. J. G. Calvert and J. N. Pitts, Jr., ref. 18, p. 429.

150. P. deMayo, Professor, U. of Western Ontario, London, Canada, personal communication.

151. J. N. Butler and G. B. Kistiakowsky, $\underline{J}$. $\underline{Am}$. $\underline{Chem}$. $\underline{Soc}$., $\underline{\underline{83}}$, 1324 (1961).

152. E. Chinoponos, $\underline{Chem}$. $\underline{Rev}$., $\underline{63}$, 247 (1963).

153. M. Jones, Jr. and K. R. Rettig, $\underline{J}$. $\underline{Am}$. $\underline{Chem}$. $\underline{Soc}$., $\underline{\underline{87}}$, 4013 (1965).

154. W. Lwowski, $\underline{J}$. $\underline{Am}$. $\underline{Chem}$. $\underline{Soc}$., $\underline{\underline{87}}$, 5490 (1965).

155. J. G. Calvert and J. N. Pitts, Jr., ref. 18, p. 466.

156. G. A. Hamilton and J. R. Glacin, $\underline{J}$. $\underline{Am}$. $\underline{Chem}$. $\underline{Soc}$., $\underline{\underline{88}}$, 1584 (1966).

157. K. F. Reid, "Properties and Reactions of Bonds in Organic Molecules," American Elsevier, Inc., New York, N. Y., 1968, p. 161.

158. J. I. G. Cadogan and M. J. Perkins in S. Patai, "The Chemistry of Alkenes," John Wiley & Sons, New York, N. Y., 1964, p. 653.

159. W. Kirmse, ref. 19, pp. 87-90.

160. M. Jones, Jr., A. Kulczycki, Jr., and K. F. Hummel, $\underline{Tetrahedron}$ $\underline{Letters}$, 183 (1967).

161. D. C. Neckers, "Molecular Organic Photochemistry," Reinhold Publishing Corp., New York, N. Y., 1967.

162. J. I. G. Cadogan and M. J. Perkins, ref. 158, p. 649.

163. J. G. Calvert and J. N. Pitts, Jr., ref. 18, p. 728.

164. R. E. Hunt and W. D. Davis, Jr., $\underline{J}$. $\underline{Am}$. $\underline{Chem}$. $\underline{Soc}$., $\underline{69}$, 1415 (1947).

165. H. J. L. Backstrom, $\underline{Naturwissenschaftan}$, $\underline{21}$, 251 (1933).

166. R. W. Murray, et al., $\underline{J}$. $\underline{Am}$. $\underline{Chem}$. $\underline{Soc}$., $\underline{\underline{84}}$, 3214 (1962).

167. W. Kirmse, ref. 19, p. 83.

168. J. D. Roberts and M. C. Caserio, "Basic Principles of Organic Chemistry," W. A. Benjamin, Inc., New York, N. Y., 1965, p. 77.

169. A. Streitwieser, Jr., "Solvolytic Displacement Reactions," McGraw Hill Book Co., New York, N. Y., 1962, p. 82.

170. R. A. Sneen and J. W. Larsen, $\underline{J}$. $\underline{Am}$. $\underline{Chem}$. $\underline{Soc}$., $\underline{\underline{91}}$, 6031 (1969).

171. C. K. Ingeld, "Structure and Mechanism in Organic Chemistry," Cornell University Press, Ithaca, New York, 1969, p. 331.

172. E. S. Gould, "Mechanism and Structure in Organic Chemistry," Holt, Rinehart, and Winston, New York, N. Y., p. 424.

173. K. T. Finley, Eastman Organic Chemical Bulletin, 41, 2 (1969).

174. J. G. Calvert and J. N. Pitts, Jr., ref. 18, p. 467.

175. C. H. Banford, J. E. Casson, and A. N. Hughes, Chem. Comm., 1096 (1967).

176. R. Bader and J. Generosa, Canad. J. Chem., 43, 1631 (1965).

177. R. W. Carr and G. B. Kistiakowsky, J. Phys. Chem., 70, 118 (1966).

178. M. J. S. Dewar and R. C. Fahey, J. Am. Chem. Soc., 85, 2245 (1963).

179. M. J. S. Dewar and R. C. Fahey, J. Am. Chem. Soc., 85, 2248 (1963).

180. J. March, "Advanced Organic Chemistry: Reactions, Mechanisms and Structure," McGraw Hill Book Co., New York, N. Y., 1968, p. 732.

181. K. Fukui and H. Fujimoto, Tetrahedron Letters, 4303 (1965).

182. S. J. Miller, "Advances in Physical Organic Chemistry," Academic Press, New York, N. Y., 1968, p. 298.

183. S. F. Cristol and E. F. Hoegger, J. Am. Chem. Soc., 79, 3438 (1957).

184. M. J. S. Dewar, Research Professor, U. of Texas, Austin, Texas, personal communication.

185. S. J. Miller, ref. 182, p. 186.

186. V. Franzen and L. Fikentscher, Ann., 617, 1 (1958).

187. G. B. R. De Graaf and G. V. De Kolk, Rec. Trav. Chim., 77, 224 (1958).

188. G. B. R. De Graaf, J. H. V. Dijck-Rothius, and G. V. De Kolk, Rec. Trav. Chim., 74, 143 (1955).

189. I. A. Dyakonov and N. B. Vinogradova, Zhur. Obshchei Khim., 23, 244 (1953).

190. W. Kirmse, ref. 19, p. 108.

191. M. Saunders and R. W. Murray, Tetrahedron, 11, 1 (1960).

192. S. Searles, Jr. and R. E. Wann, Tetrahedron Letters, 33, 2899 (1965).

II. THE POLAR ADDITION OF DBr TO BICYCLO-[2.2.2]-OCTENE

BACKGROUND AND HISTORICAL REVIEW

Prior to 1960 the stereochemistry of the polar addition of hydrogen halides to olefins had received very little attention. Since additions to α,β-unsaturated acids,[1] 1,2-dimethylcyclopentene,[2] and 1,2-dimethylcyclohexene[3] were known to give the trans adducts, it was generally thought that hydrogen halide polar additions took place stereospecifically trans.[4] The popular explanation for the observed trans stereochemistry involved a proton π-complex mechanism.[4]
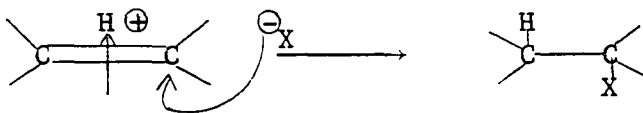
Scheme 1

Dewar and Fahey sought to gain more evidence for π-complex intermediates, and in 1962 initiated study of the polar addition of deuterium halide to acenapthylene,[4] indene,[5] and 1-phenylpropene.[6] If π-complexes were involved only trans addition product would be found. These

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substrates were chosen so that no ambiguity would arise concerning possible steric effects.[4] They were surprised to find predominant, 80-90%, _cis_ addition. A carbonium ion mechanism involving formation of a tight ion pair with stereoselective _cis_ collapse to form product was postulated.
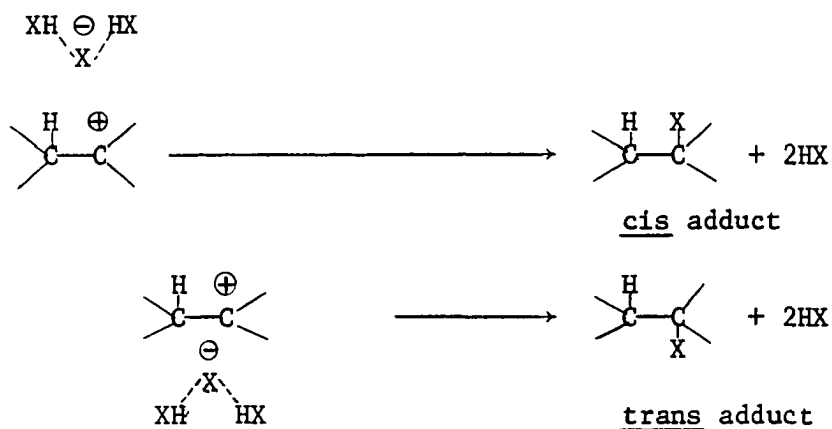
Scheme 2

Due to these results Dewar and Fahey suggested that in general proton π-complex formation was unfavorable relative to carbonium ion formation and supported this view with a simple bond energy consideration.[5]

$$E_I = A + E_{C-C} + E_{C-H}$$

$$E_{II} = A + E_{C-C} + E_{\pi-H}$$

$$E_I = \text{Total Bond Energy of I}$$

$$E_{II} = \text{Total Bond Energy of II}$$

A = Sum of the Bond Energies of the Other Bonds (which are the same in I and II)

$$E_I = A + 83 + E_{C-H}$$

$$E_{II} = A + 147 + E_{\pi-H}$$

Inspection of these latter two equations reveals that for E_I to be > E_{II} then E_{C-H} must be > $64 + E_{\pi-H}$. This is indeed the case since E_{C-H} = 99 and $E_{\pi-H}$ < 35. The conclusion, therefore, is that formation of I is more favorable than formation of II.

Since this pioneering work of Dewar and Fahey additional evidence has been accumulated which tends to support the idea that proton π-complexes are not key intermediates in HX additions to olefins. Thus, several other substrates have been found which add HX predominantly cis, including
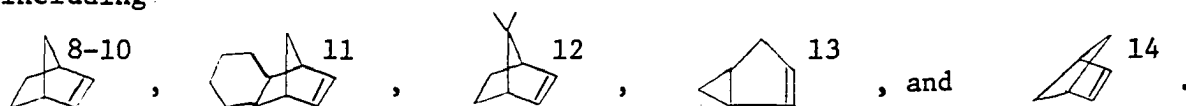
Furthermore, in those cases where predominant trans additions have been observed,
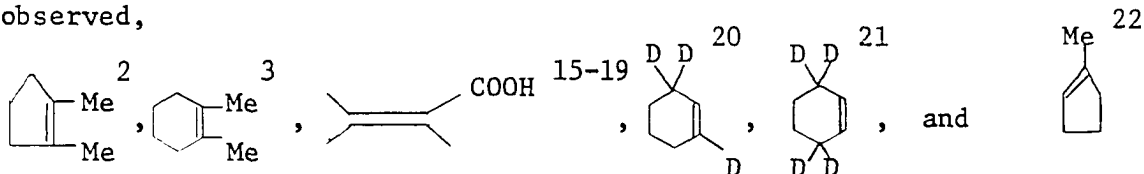
the favored mechanisms today[23] usually involve either (a) intermediate tight carbonium ion formation with stereoselective trans collapse (for steric reasons) or (b) a termolecular mechanism involving both C-H and C-X bond formation in the transition state.
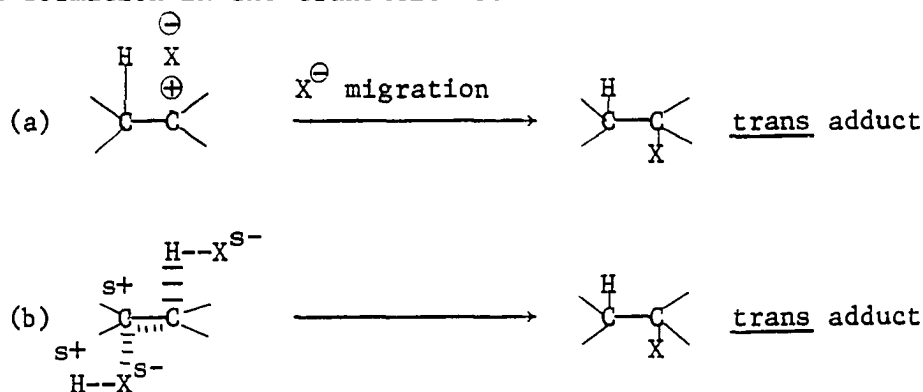
Scheme 3

Although nobody has obtained evidence which <u>requires</u> a proton π-complex as an intermediate in acid additions,[23] it must be emphasized that whenever highly stereoselective or stereospecific <u>trans</u> HX addition to olefins is observed one must <u>a priori</u> consider the possibility of a proton π-complex intermediate.

Unfortunately, the mechanisms of addition to many of the olefin substrates studied are either complicated by steric factors which cloud the interpretation or else have structural features such as an α-electron releasing group (i.e., aryl, methyl, cyclopropyl, etc.) which tips the scales against a proton π-complex in favor of a classical carbonium ion.[13]

One notable exception to these liabilities is cyclohexene. Thus, it appears free of steric or electronic factors that might prejudice it in favor of one particular stereochemical mode of addition. Fahey has found that 85% <u>trans</u> addition occurs.[24] This suggests a possible π-complex intermediate. Kinetic data, however, indicated that mechanism (b) of Scheme 3 must be involved in formation of the <u>trans</u> adduct.[25] The rate expression found was $V = k(\text{olefin}) (\text{HX})^2$. Furthermore, when tetramethylammonium chloride was added a significant rate enhancement occurred which was too large to be attributed to a normal salt effect. This indicated that both the C-H and C-X bonds must be forming in the transition state. A competing bimolecular mechanism accounted for the minor <u>cis</u> adduct.

RESULTS AND DISCUSSION

We have selected for study an olefin, bicyclo-[2.2.2]-octene,
that also (as with cyclohexene) a priori appears free of stereochemical
prejudice. In order to determine the stereochemistry of the reaction we
labelled the atoms isotopically using deuterium bromide. Addition was
carried out at -78° in pentane with exclusion of light and using a large
excess of DBr. The reaction product was analyzed by nuclear magnetic
resonance (see Figure 1). The nmr analysis involved measurement of the
splitting of the CHBr proton signal due to interaction with the adjacent
CHD proton. Peak resolution was improved by partial decoupling of the
CHBr proton with bridge and bridgehead protons. The NMR spectrum immedi-
ately showed the predominance of the cis adduct (0° dihedral bond angle
between the C-H bonds, therefore, an expected large coupling constant
of ca. 6-9 cps[26]). The amount of trans adduct (120° dihedral angle
between the C-H bonds, therefore, an expected small coupling constant
of ca. 2-3 cps[26]) was small and the peaks poorly resolved. Nevertheless,
the ratio of cis to trans adduct could be estimated by peak height mea-
surements. These calculations indicated 80±5% cis and 20±5% trans
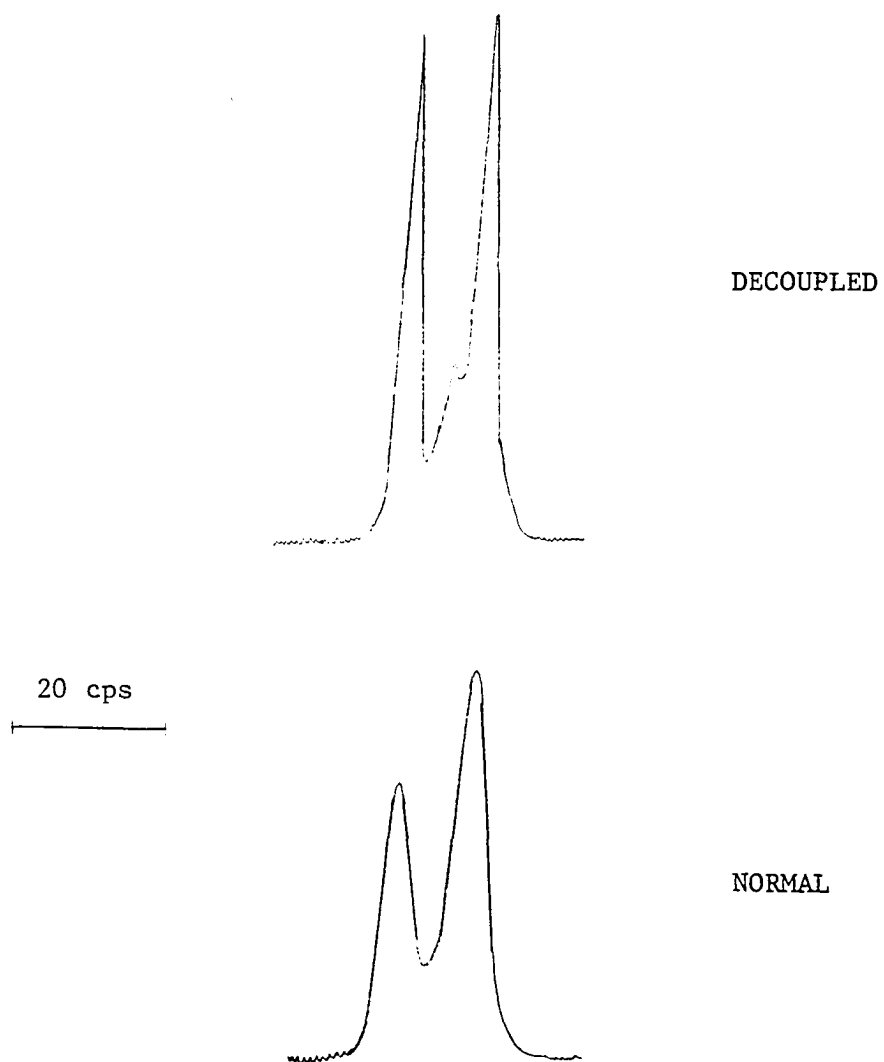adduct.

Figure 1. CHBr proton of 2-bromo-3-d-bicyclo-[2.2.2]-octane of 80% cis, 20% trans composition: bottom, normal; top, decoupled.

The amount of <u>trans</u> adduct, 20±5%, formed provides a valuable insight into the reaction mechanism. First, we established that the <u>trans</u> isomer was formed as a primary reaction product, and not by secondary isomerization, by allowing the reaction mixture to stand for various lengths of time before work-up. The <u>cis</u> to <u>trans</u> isomerization of the bromide in the reaction solution was so slow as to be imperceptible even upon very long standing. Thus, the <u>cis</u>/<u>trans</u> ratio remained unchanged. Furthermore, we established that the <u>trans</u> isomer was not formed by a competing free radical process, for the proportion of <u>cis</u> and <u>trans</u> adducts remained unchanged when free radical inhibitor was added to the reaction mixture.

Traylor[27] has postulated a theory concerning strained bicyclic systems such as and . He suggested that these substrates should add HX stereospecifically <u>cis</u> via a "polarized molecular addition" due to the geometric restriction which hinders <u>trans</u> addition. Thus, due to the rigidity of the bicyclic skeleton, severe twist strain is imposed in the co-planar transition state leading to <u>trans</u> addition.
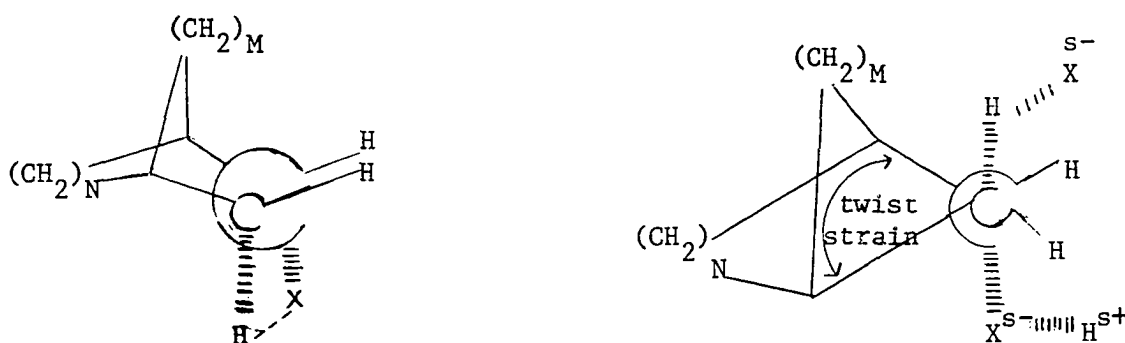
<u>cis</u> "polarized molecular addition"   <u>trans</u> co-planar addition

Figure 2

Experimentally, it has been found by F. T. Bond[28] that DCl does indeed add completely cis to . Our findings, however, of a significant amount, 20±5%, of trans DBr addition to bicyclo-[2.2.2]-octene, , is not in accord with Traylor's "polarized molecular addition" which predicts completely cis product.

Completely different competing mechanisms may actually be involved in leading to our observed cis and trans adducts. Nevertheless, an appealing alternative involving one key intermediate exists; namely, a tight carbonium ion pair, which collapses preferentially but not exclusively cis.
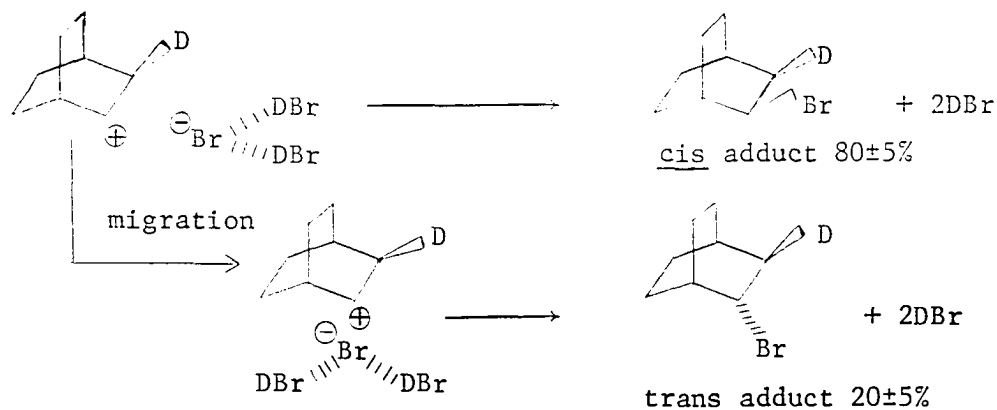
Scheme 4

It has occurred to us that such an intermediate might lead to some skeletal rearrangement to a [3.2.1] adduct. Analysis by nmr, vpc, and derivative formation, however, failed to detect any skeletal rearranged adduct. Although the solvolysis reactions of bicyclo-[2.2.2]-octyl derivatives are known to be accompanied by skeletal rearrangement,[29] these undoubtedly involve free dissociated carbonium ions. It is now recognized, however, that tight ion pairs possess properties differing considerably from free dissociated carbonium ions. In particular they may be expected to be much less prone to rearrange due to their shorter lifetime and

because of the electrostatic stabilization between the positive charge in the alkyl moiety and the negative counteranion.[30]

SUMMARY AND CONCLUSIONS

The polar addition of deuterium bromide to bicyclo-[2.2.2]-octene in pentane at $-78°$ has been found to proceed stereoselectively to give 80±5% cis and 20±5% trans 2-bromo-3-d-bicyclo-[2.2.2]-octane.

The trans adduct was formed as a primary reaction product not by a secondary isomerization. Neither was the trans isomer formed by a competing free radical process. No adduct resulting from [2.2.2] to [3.2.1] skeletal rearrangement was formed.

Our results are suggestive of the tight ion pair mechanism originally postulated by Dewar and Fahey[4-6] to explain predominant but not exclusive cis hydrogen halide addition to olefins.

EXPERIMENTAL

Materials and Methods. Chemicals used and their suppliers are

listed below.

        Acetone, reagent grade, Fisher
        Bicyclo-[2.2.2]-octene, 99% pure, Columbia Organic Chemicals
        t-Butyl alcohol, highest purity grade, Eastman
        2,6 di-t-Butylphenol, Ethyl Corp.
        Dimethylformamide, reagent grade, Mallinckrodt
        Deuterium Oxide, 99.8% pure, Diaprep, Inc.
        Lithium Carbonate, reagent grade, Fisher
        Magnesium sulfate, anhydrous, B&A
        Pentane, 98% pure, MC&B
        Phosphorus tribromide, practical grade, Eastman
        Silver bromide, prepared from LiBr (MC&B) and $AgNO_3$ (B&A)
        Sodium metal, Fisher
        Tetrahydrofuran, reagent grade, Baker

All melting points are corrected. Sealed capillaries were used

in the melting point determinations which were made with a Thomas Hoover

Melting Point Apparatus. Gas chromatography work was performed using

a Varian Aerograph Model 90-P instrument with a thermal conductivity de-

tector and a Varian Aerograph Model 1200 with a flame ionization detector.

Both employed helium carrier gas. Infrared spectra were recorded using

a Beckman IR 8 Spectrophotometer. Nuclear magnetic resonance spectra

were recorded on a Varian A-60 Spectrophotometer equipped with a spin de-

coupler and using tetramethylsilane as the internal standard.

Preparation of Deuterium Bromide. Deuterium bromide was prepared

by addition of deuterium oxide to phosphorus tribromide. The reaction was

-133-

carried out in a three-neck reaction flask and the DBr collected in a

trap as formed. The deuterium halide was partially distilled trap to

trap before use. Traps were cooled in Dry Ice-acetone.

Addition of Deuterium Bromide to Bicyclo-[2.2.2]-octene. To a

tall 500 ml gas washing bottle fitted with a drying tube was added 1 g

(9.25 mm) of bicyclo-[2.2.2]-octene and 150 ml of pentane. The reaction

vessel was immersed in a Dry Ice-acetone bath and light was excluded.

A stopcock was opened and ca. 340 mm of previously prepared deuterium

bromide was allowed to distill into the reaction mixture over a period

of 6 hours. The reaction mixture was allowed to stand 24 hours. Removal

of solvent and excess deuterium bromide via a rotary evaporator left a

white solid.

Reactions on a larger scale were run in the same manner except

that the reaction mixture was allowed to stand for 1-5 days. The pro-

duct obtained was sublimed to give in 75-85% yield a waxy solid, mp

64-65° (lit. for 2-bromobicyclo[2.2.2]octane[31] 64-65.5°). Mass spectro-

metric analysis indicated very high isotopic purity (i.e., only d_1, no

detectable d_o).

N.m.r. Analysis of Cis to Trans Ratio. The 2-bromo-3d-bicyclo-

[2.2.2]-octane was analyzed by nuclear magnetic resonance (see Figure 1).

This involved measurement of the splitting of the CHBr proton signal,

δ 4.42, due to interaction with the adjacent CHD proton. Peak resolution

was improved by partial decoupling of the CHBr proton with bridge and

bridgehead protons. The nmr spectrum immediately showed the predominance

of the cis adduct (0° dihedral bond angle between the C-H bonds; therefore,

an expected large coupling constant of ca. 6-9 cps[32]). The amount of trans

adduct ($120°$ dihedral angle between the C-H bonds, therefore, an expected small coupling constant of _ca._ 2-3 cps[32]) was small and the peaks poorly resolved. Nevertheless, the ratio of _cis_ to _trans_ adduct could be estimated by peak height measurements via the method of Dewar and Fahey.[33] These calculations indicated 80±5% _cis_ and 20±5% _trans_ adduct.

Addition of Deuterium Bromide to Bicyclo-[2.2.2]-octene With
Added Free-Radical Inhibitor. The normal procedure was used except that .1 g of 2,6 di-_t_-butylphenol was added. The product composition as determined by nmr analysis was the same as obtained previously without added free radical inhibitor.

Cis to Trans Isomerization in the Reaction Solution. The reaction solution was allowed to stand for various lengths of time before work-up. The _cis_ to _trans_ isomerization of the bromide in the reaction solution containing the huge excess of deuterium bromide was so slow as to be imperceptible even upon very long standing. Thus, the _cis_/_trans_ ratio remained unchanged.

Attempted Isomerization of 2-Bromo-3-d-bicyclo-[2.2.2]-octane
to a 50/50 Cis/Trans Mixture. Various attempts were made to isomerize the 80% _cis_/20% _trans_ 2-bromo-3-_d_-bicyclo-[2.2.2]-octane to a 50/50 mixture. These efforts involved treatment with lithium bromide in acetone and dimethylformamide at various temperatures. Interference due to partial competing elimination and presumably skeletal rearrangement negated the results.

Addition of Hydrogen Bromide to Bicyclo-[2.2.2]-octene. The normal procedure was used as previously described for the addition of deuterium bromide.

Dehydrobromination of 2-Bromobicyclo-⌈2.2.2⌉-octane. A solution
of sodium t-butoxide was prepared by adding .8 g (34.8 mm) of sodium to
25 ml of dry t-butyl alcohol and refluxing overnight. Then 1 g (5.3 mm)
of 2-bromo-bicyclo-⌈2.2.2⌉-octane was added and the solution refluxed
for 36 hours. The solution was dumped into 50 ml of ice water and ex-
tracted twice with 25 ml portions of pentane. The combined pentane ex-
tracts were extracted 10 times with 20 ml portions of water to remove
t-butyl alcohol. After drying over anhydrous magnesium sulfate the pen-
tane solution was filtered and the pentane removed by distillation on
a steam bath. The residue was sublimed and 145 mg (1.34 mm, 25.3%) of
bicyclo-⌈2.2.2⌉-octene obtained, mp 116-117° (lit. 112-113°,[34] 113-114.5°,[35]
116-117.5°[36]). Infrared and nuclear magnetic resonance spectra were iden-
tical with that of an authentic sample and vpc analysis on SE-30 and
Dimethyl Sulfolane columns showed only one peak.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas
chromatograph using a 5' x 1/4" metal column packed with 20% SE 30 on
Chromsorb W Regular 60/80, operating at 60°, detector 160°, filament
current 100 ma, helium flow rate 120 cm^3/min. Also used was a 10' x 1/4"
metal column packed with 40% Dimethyl Sulfolane on Chromsorb W Regular
60/80, operating at 60°, detector 160°, filament current 100 ma, helium
flow rate 120 cm^3/min.

Sodium and Alcohol Reduction of 2-bromobicyclo-⌈2.2.2⌉-octane.
Sodium metal (.85 g, 37 mm) was added to a solution containing 1 g (5.3 mm)
2-bromobicyclo-⌈2.2.2⌉-octane in 12 ml of dry tetrahydrofuran and 3 ml
of dry t-butyl alcohol and the mixture refluxed for 48 hours. The reac-
tion mixture was filtered (to remove unreacted sodium) into 40 ml of ice

water and extracted twice with 25 ml portions of pentane. The combined

pentane extracts were extracted 10 times with 20 ml portions of water to

remove tetrahydrofuran and t-butyl alcohol. After drying over anhydrous

magnesium sulfate the pentane solution was filtered and the pentane re-

moved by distillation on a steam bath. The residue was sublimed and

340 mg (3.1 mm, 58.5%) of bicyclo-[2.2.2]-octane obtained, mp 167-168°

(lit. 166-168°,[37] 168-171°,[38] 169-170°,[39] 169-171.5°[35]). Vpc analysis

using an SE-30 column indicated (by peak enhancement) the presence of

3.4% bicyclo-[2.2.2]-octene. This slight impurity was also reflected

in the infrared spectrum (15% CCl_4 solution) which showed an extraneous

absorption at 693 cm^{-1} where an authentic sample of bicyclo-[2.2.2]-octene

was found to absorb very strongly.

Vpc analysis was performed on a Varian Aerograph Model 90-P gas

chromatograph using a 5' x 1/4" metal column packed with 20% SE 30 on

Chromsorb W Regular 60/80, operating at 60°, detector 160°, filament

current 100 ma, helium flow rate 120 cm^3/min. By employing a standard

solution it was found that area per cent equalled weight per cent.

Hydrolysis of 2-Bromobicyclo[2.2.2]octane. A mixture of .31 g

(1.64 mm) of 2-bromobicyclo-[2.2.2]-octane, .3 g (4.06 mm) of lithium

carbonate, and 6 ml of water was heated at reflux for 3 days with stirring

by means of a magnetic stirrer. About 2 ml of acetone was added to the

refluxing mixture to prevent accumulation of bicyclic material in the

condenser. The reaction solution was diluted with 20 ml of water and

extracted twice with 25 ml portions of pentane. The combined pentane

extracts were washed with water, dried over anhydrous magnesium sulfate,

and the pentane removed by distillation on a steam bath. The residue

was sublimed and 135 mg (1.07 mm, 65.2%) of product obtained, mp 206-208°

(lit. mp for bicyclo-[2.2.2]-octane-2-ol 212-214°,[37] 208-210°,[40] 217-219°,[41]

221-222°[36]). According to the literature,[42] the column described below

would separate the [2.2.2] alcohol from each of the isomeric [3.2.1] alcohols.

Two peaks were observed in the ratio 47.6 and 52.4% identified on the basis

of elution order[42] respectively as the exo[3.2.1] and [2.2.2] isomers.

Vpc analysis was performed on a Varian Aerograph Model 1200 gas

chromatograph using a 10' x 1/8" metal column packed with 25% Diglycerol

on Chromsorb W Regular 60/80 operating at 130°, detector 190°, helium

flow rate 120 cm^3/min.

Attempted Rearrangement of 2-Bromobicyclo-[2.2.2]-octane to

2-Bromo-bicyclo-[3.2.1]-octane. A solution containing 1 g (5.3 mm)

of 2-bromobicyclo-[2.2.2]-octane and 1 g (5.32 mm) of AgBr in 8 ml of

CCl_4 was refluxed for various lengths of time up to 6 days. This pro-

cedure according to Doering[31] results in total skeletal rearrangement

with formation of the [3.2.1] adduct, mp 39-41°. We were unable to dupli-

cate this reported result.

Bicyclo-[2.2.2]-octane. A 1.0 g (9.26 mm) sample of bicyclo-[2.2.2]-

octene was hydrogenated on a Parr Hydrogenator at 3 atmospheres pressure in

40 ml of absolute ethanol employing 60 mg of platinum oxide as catalyst.

After 2 hours the catalyst was removed by filtration and 50 ml of ice water

added. This solution was extracted twixe with 25 ml portions of pentane.

The combined pentane extracts were extracted 10 times with 20 ml portions

of water to remove ethanol. After drying over anhydrous magnesium sul-

fate the pentane dolution was filtered and the pentane removed by distil-

lation on a steam bath. The residue was sublimed and 466 mg (4.23 mm, 45.7%)

of bicyclo-[2.2.2]-octane obtained, mp 172-173° (lit. 166-168°,[37] 168-171°,[38]

169-170°,[39] 169-171.5°[35]).

BIBLIOGRAPHY

1. W. R. Vaughan, R. L. Craven, R. Q. Little, and A. C. Schoenthaler, J. Am. Chem. Soc., 77, 1594 (1955).

2. G. S. Hammond and C. H. Collins, J. Am. Chem. Soc., 82, 4323 (1960).

3. G. S. Hammond and T. D. Nevitt, J. Am. Chem. Soc., 72, 4121 (1954).

4. M. J. S. Dewar and R. C. Fahey, J. Am. Chem. Soc., 85, 2245 (1963).

5. M. J. S. Dewar and R. C. Fahey, J. Am. Chem. Soc., 85, 2248 (1963).

6. M. J. S. Dewar and R. C. Fahey, J. Am. Chem. Soc., 85, 3645 (1963).

7. M. J. S. Dewar and R. C. Fahey, Angewandte Chemie, International English Edition, 3 (4), 245 (1964).

8. H. Kwart and J. L. Nyce, J. Am. Chem. Soc., 86, 2601 (1964).

9. J. K. Stille, F. M. Sonnenberg, and T. H. Kinstle, J. Am. Chem. Soc., 88, 4922 (1966).

10. H. C. Brown and K. T. Liu, J. Am. Chem. Soc., 89, 3900 (1967).

11. S. J. Cristol and R. Caple, J. Org. Chem., 31, 2741 (1966).

12. H. C. Brown and K. T. Liu, J. Am. Chem. Soc., 89, 3898 (1967).

13. P. K. Freeman, F. A. Raymond, and M. F. Grostic, J. Org. Chem., 32, 24 (1967).

14. F. T. Bond, J. Am. Chem. Soc., 90, 5326 (1968).

15. W. R. Vaughan and K. M. Milton, J. Am. Chem. Soc., 74, 5623 (1952).

16. W. R. Vaughan, R. L. Craven, R. Q. Little, and A. C. Schoenthaler, J. Am. Chem. Soc., 77, 1594 (1955).

17. W. R. Vaughan and R. Caple, J. Am. Chem. Soc., 86, 4928 (1964).

18. W. R. Vaughan, R. Caple, J. Csapilla, and P. Scheiner, J. Am. Chem. Soc., 87, 2204 (1965).

19. R. Caple and W. R. Vaughan, Tetrahedron Letters, 4067 (1966).

20. R. C. Fahey and R. A. Smith, J. Am. Chem. Soc., 86, 5035 (1964).

21. S. Wolfe and P. G. C. Campbell, private communication to R. C. Fahey.

22. Y. Pocker and K. D. Stevens, J. Am. Chem. Soc., 91, 4205 (1969).

23. R. C. Fahey in E. L. Eliel and N. S. Allinger's, "Topics in Stereo-chemistry," Interscience Publishers, New York, N. Y., 1968, p. 249.

24. R. C. Fahey and R. A. Smith, J. Am. Chem. Soc., 86, 5035 (1964).

25. R. C. Fahey in E. L. Eliel and N. L. Allinger's, ref. 23, p. 248.

26. M. Karplus, J. Chem. Physics, 30, 11 (1959).

27. T. G. Traylor, Accounts of Chemical Research, 2 (5), 152 (1969).

28. F. T. Bond, J. Am. Chem. Soc., 90, 5326 (1968).

29. H. Kwart and J. L. Irvine, J. Am. Chem. Soc., 91, 5541 (1969).

30. R. A. Sneen and J. W. Larsen, J. Am. Chem. Soc., 91, 6031 (1969).

31. W. von E. Doering and M. Farber, J. Am. Chem. Soc., 71, 1514 (1949).

32. M. Karplus, J. Chem. Physics, 30, 11 (1959).

33. M. J. S. Dewar and R. C. Fahey, J. Am. Chem. Soc., 85, 2245 (1963).

34. A. F. Bickel, J. Knotnerus and G. C. Vegter, Tetrahedron, 9, 230 (1960).

35. N. A. LeBel, J. E. Huber, and L. H. Zalkow, J. Am. Chem. Soc., 84, 2226 (1962).

36. H. L. Goering and M. F. Sloan, J. Am. Chem. Soc., 83, 1397 (1961).

37. H. M. Walborsky, Experientia, 9, 209 (1953).

38. H. M. Walborsky and D. F. Loncrini, J. Am. Chem. Soc., 76, 5396 (1954).

39. K. Alder and G. Stein, Ann, 514, 1 (1934).

40. A. A. Youssef, M. E. Baum, and H. M. Walborsky, J. Am. Chem. Soc., 81, 4709 (1959).

41. J. E. Berson and D. Willner, J. Am. Chem. Soc., 86, 609 (1964).

42. H. Kwart and J. L. Irvine, J. Am. Chem. Soc., 91, 5541 (1969).