Reactions of Carbonyl Ylides

J. W. Lown and K. Matsumoto[1]
Department of Chemistry, University of Alberta, Edmonton 7, Alberta

Received June 22, 1971

2,3-Diphenylindenone oxide **1** undergoes thermal 1,3-dipolar cycloadditions via a carbonyl ylide with symmetrical olefinic dipolarophiles to give (*i*) with *cis* addends mixtures of *endo* and *exo* adducts in which *endo* adducts generally predominate in agreement with results obtained with 1-cyclohexyl-6-(cyclohexylimino)-1*a*-phenylindano[1,2-*b*]aziridine and (*ii*) with *trans* addends adducts in which the 2-*exo*-3-*endo* product predominates. The pyrilium oxide **4** is efficiently trapped with benzyne. 1,3-Diphenylisobenzofuran reacts with *cis*-addends to give *endo–exo* mixtures in which the *endo* adducts generally predominate. 2-Acetyl-5,5-pentamethylene-2-phenyl-Δ^3-1,3,4-oxadiazoline undergoes regiospecific cycloaddition via a carbonyl ylide with unsymmetrical olefinic dipolarophiles in accordance with substituent electronic effects, and with 1,4-naphthoquinone a previously postulated type of intermediate adduct is isolated.

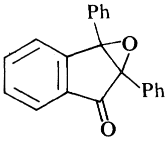
L'oxyde de diphénylindenone-2,3 **1** peut réagir pour donner des cycloadditions dipolaires-1,3 thermiques, par l'intermédiaire d'une ylure de carbonyle possédant des dipolarophiles oléfiniques symétriques. On obtient ainsi (*i*) avec des mélanges *endo* et *exo* des produits *cis*, des produits d'addition où la forme *endo* prédomine habituellement, en accord avec les résultats obtenus avec le cyclohexyl-1 (cyclohexylimino)-6 phénylindano-1*a* aziridine[1,2-*b*] et (*ii*) avec les produits *trans*, des produits d'addition où la forme *exo*-2-*endo*-3 prédomine. L'oxyde de pyrilium **4** peut être recueilli efficacement dans le benzène. Le diphénylisobenzofuranne réagit avec les produits *cis* pour donner des mélanges *endo–exo*, où les produits d'addition *endo* prédominent généralement. Le 2-acétyl-5,5 pentamethylène-2 phényl-Δ^3-1,3,4-oxadiazoline peut réagir pour donner des cycloadditions régiospécifiques, via une ylure de carbonyle possédant des dipolarophiles oléfiniques non-symétriques, selon les effets électroniques du substituant; avec la naphthoquinone-1,4, on isole un produit d'addition intermédiaire postulé précédemment.

Canadian Journal of Chemistry, 49, 3443 (1971)

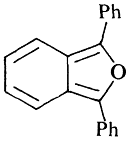
Introduction

Examination of the orbital symmetry controlled generation of azomethine ylides from aziridines and exploration of their synthetic potential via 1,3-dipolar cycloaddition to a wide variety of multiple and heteromultiple bonds has recently proved extremely fruitful (1–18). The isoelectronic carbonyl ylides which are of equal importance have not received as much attention (19–29). Strong evidence has been obtained for the predicted (30) thermal conrotatory (27) and the photochemical disrotatory (26, 27) opening of suitable oxirane precursors to carbonyl ylides. We report an examination of the cycloaddition reactions of certain carbonyl ylides with reference to their stereochemistry, regiospecificity (31), steric, and electronic requirements.

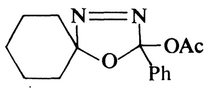
The model compounds chosen as carbonyl ylide precursors were **1**, **2**, and **3**, affording an opportunity to examine these dipoles under as wide a range of reaction conditions as possible. The thermally induced tautomerization of **1** to **4** was reported by Ullmann and Milks (22) and species **4** was shown to react as a carbonyl ylide in 1,3-dipolar cycloaddition to give, with norbornadiene, an adduct which was assigned the *exo* structure **5**.



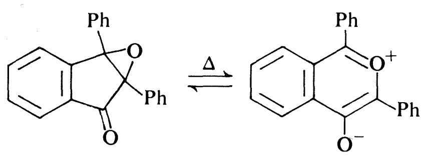
1

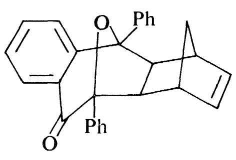


2



3



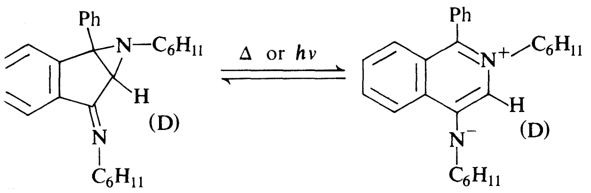


5

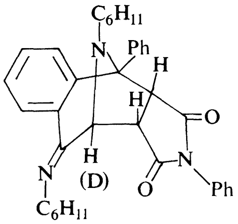
---

[1] NRCC Postdoctorate Fellow, 1969 to present.

The isoelectronic 1-cyclohexyl-6(cyclohexylimino)-1*a*-phenylindano[1,2-*b*]aziridine (**6**) was recently shown by Lown and Matsumoto (32) to undergo valence tautomerization both thermally and photochemically to the isoquinolinium imine **7**. The azomethine ylide species **7** was trapped efficiently by olefinic dipolarophiles to give exclusively *endo* adducts, *e.g.* **8**. The diametrically opposed configurational results obtained with **1** and **6** posed the questions of (*i*) whether this reflected a fundamental difference in properties of the apparently similar species of carbonyl ylides and azomethine ylides or whether (*ii*) other factors operating in **7** (*e.g.* steric hindrance from the *N*-substituent) accounted for the differences observed. However since identical results, *i.e.* exclusively *endo* adducts, are obtained with N—CH_3 analogs of **6** the problem required further investigation. Also in view of the controversy attending the mechanism of the Diels–Alder reaction it was of interest to determine if a trend towards general *endo* adduction also obtains in the related 1,3-dipolar cycloaddition reaction.



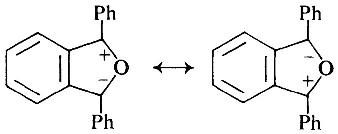
6 **7**



8

Results and Structural Assignments

Unlike the situation with **6**, wherein specific deuterium labelling allowed an unambiguous assignment of configuration by examination of the n.m.r. coupling constants (33) a similar method could not be applied to the adducts of **1**. Although diphenylisobenzofuran is normally regarded as a diene, contribution of resonance forms such as those shown below allow one to regard it as a masked carbonyl ylide (28). Accordingly several 1,3-dipolar cycloaddition adducts were prepared in parallel from **1** and **2** for comparison and to aid in the n.m.r. assignments. The cycloaddition of dienophiles to **2** has been observed to give predominantly *endo*-adduction with pyracycloquinone and pyracyclene (33); *exo*-addition with cyclopropene (34), norbornadiene and norbornene (35), and predominantly *exo*-addition with chlorocyclopropene (36). In the latter case, which has been substantiated by Battiste and Sprouse (34), *endo* protons in the adducts were shielded by the benzene ring relative to the *exo* protons which is consistent with n.m.r. observations in other similar bicyclic adducts (37). The stereochemistry of the adducts of **2** have been assigned on this basis.



A number of other relationships became apparent upon examining the n.m.r. spectra of many adducts of **1** and **2**.

(*1*) For adducts of **2**: (protons) δ *exo* > *endo*; and (methylester) δ *endo* > δ *exo*.

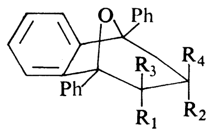
(*2*) For adducts of **1**: (*i*) *J cis* (2-*exo*-3-*exo*) > *J cis* (2-*endo*-3-*endo*); (*ii*) *J trans* (2 *endo*-3-*exo*) > *J trans* (2 *exo*-3-*endo*); (*iii*) from protons, δ 3-*exo* > δ 3-*endo*; δ 2-*exo* > δ 2-*endo*; (*iv*) For *trans* adducts of **1**, Δ(δ 2-*endo*-3-*exo*) > Δ(δ 2-*exo*-3-*endo*) (see Table 3).

While these observations are empirical they serve as a check for internal consistency in the stereochemical assignment.

To obtain an accurate determination of isomeric proportion in the products, n.m.r. spectra were taken on the initially obtained mixtures before attempted purification.

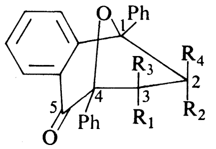
Reaction of **2** separately with *cis*- and *trans*-1,2-dichloroethylene gave one adduct in each case, the product of the former being assigned the *endo* structure **9***a*. Similarly only one adduct **10***a* was obtained upon addition of *cis*-1,2-dichloroethylene with **1**.

Addition of *trans*-1,2-dichloroethylene afforded an isomeric mixture of **10***b* and *c* in the ratio of 1:4 in which the 2-*exo*-3-*endo* product predominates. Comparison of the methine proton chemical shifts and coupling constants with those of **9***a* and *b* allows assignments to be made and shows no evidence of epimerization indicating



9

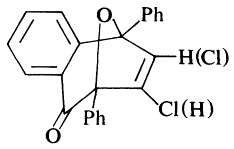
a $R_1 = R_2 = \mathrm{Cl}$; $R_3 = R_4 = \mathrm{H}$
b $R_1 = R_4 = \mathrm{H}$; $R_2 = R_3 = \mathrm{Cl}$
c $R_1 = R_2$ = 1,8-naphthyl; $R_3 = R_4 = \mathrm{H}$
d $R_1 = R_2 = \mathrm{H}$; R_3, R_4 = 1,8-naphthyl
e R_1, R_2 = OCOO; $R_3 = R_4 = \mathrm{H}$
f $R_1 = R_2 = \mathrm{H}$; R_3, R_4 = OCOO
g R_1, R_2 = CONPhCO; $R_3 = R_4 = \mathrm{H}$
h $R_1 = R_4 = \mathrm{H}$; $R_2 = R_3 = \mathrm{CO_2CH_3}$
i $R_1 = R_2 = \mathrm{CO_2CH_3}$; $R_3 = R_4 = \mathrm{H}$
j $R_1 = R_4 = \mathrm{H}$; $R_2 = R_3 = \mathrm{CN}$
k $R_1 = R_4 = \mathrm{H}$; $R_2 = R_3 = \mathrm{COPh}$
l $R_1 = \mathrm{CN}$; $R_2 = \mathrm{CH_3}$; $R_3 = R_4 = \mathrm{H}$



10

a $R_1 = R_2 = \mathrm{Cl}$; $R_3 = R_4 = \mathrm{H}$
b $R_1 = R_4 = \mathrm{H}$; $R_2 = R_3 = \mathrm{Cl}$
c $R_1 = R_4 = \mathrm{Cl}$; $R_2 = R_3 = \mathrm{H}$
d R_1, R_2 = 1,8-naphthyl; $R_3 = R_4 = \mathrm{H}$
e $R_1 = R_2 = \mathrm{H}$; R_3, R_4 = 1,8-naphthyl
f R_1, R_2 = OCOO; $R_3 = R_4 = \mathrm{H}$
g $R_1 = R_2 = \mathrm{H}$; R_3, R_4 = OCOO
h R_1, R_2 = COOCO; $R_3 = R_4 = \mathrm{H}$
i R_1, R_2 = CONPhCO; $R_3 = R_4 = \mathrm{H}$
j $R_1 = R_4 = \mathrm{CO_2CH_3}$; $R_2 = R_3 = \mathrm{H}$
k $R_1 = R_4 = \mathrm{H}$; $R_2 = R_3 = \mathrm{CO_2CH_3}$
l $R_1 = R_2 = \mathrm{H}$; $R_3 = R_4 = \mathrm{CO_2CH_3}$
m $R_1 = R_2 = \mathrm{CO_2CH_3}$; $R_3 = R_4 = \mathrm{H}$
n $R_1 = R_4 = \mathrm{Ph}$; $R_2 = R_3 = \mathrm{H}$
o $R_1 = R_4 = \mathrm{H}$; $R_2 = R_3 = \mathrm{Ph}$
p $R_1 = R_4 = \mathrm{CN}$; $R_2 = R_3 = \mathrm{H}$
q $R_1 = R_4 = \mathrm{H}$; $R_2 = R_3 = \mathrm{CN}$
r $R_1 = R_4 = \mathrm{COPh}$; $R_2 = R_3 = \mathrm{H}$
s $R_1 = R_2 = \mathrm{Ph}$; $R_3 = R_4 = \mathrm{H}$
t $R_1 = R_2 = \mathrm{H}$; $R_3 = R_4 = \mathrm{Ph}$
u $R_1 = \mathrm{CN}$; $R_2 = \mathrm{CH_3}$; $R_3 = R_4 = \mathrm{H}$
v $R_1 = \mathrm{CN}$; $R_2 = R_3 = R_4 = \mathrm{H}$
w R_1, R_2 = CONHCO, $R_3 = R_4 = \mathrm{H}$

stereospecific cycloadditions. The *cis*-configuration of **10***a* was confirmed by the facile *trans*-elimination of hydrogen chloride upon recrystallization to give **11** in which the direction of elimination is not determined. Compounds **10***b* and *c* in contrast were quite stable to heating and showed no tendency to eliminate hydrogen chloride.



11

Diphenylisobenzofuran **2** reacted with acenaphthylene to give an isomeric mixture of the *endo* and *exo* adducts **9***c* and *d* in the ratio of 3:1. Trost recently reported reaction of **2** with the closely analogous pyracycloquinone to give an *endo*:*exo* ratio of 3:1 (33). The *exo* methine protons in the latter case resonate at δ 5.42 closely comparable with the analogous protons in **9***c* at 5.12, supporting the structural assignments. The indenone oxide **1** afforded with acenaphthylene a mixture of the analogous adducts **10***d* and *e* in the *endo*:*exo* proportion of 3:2 suggesting **2** is a good analog of **1**.

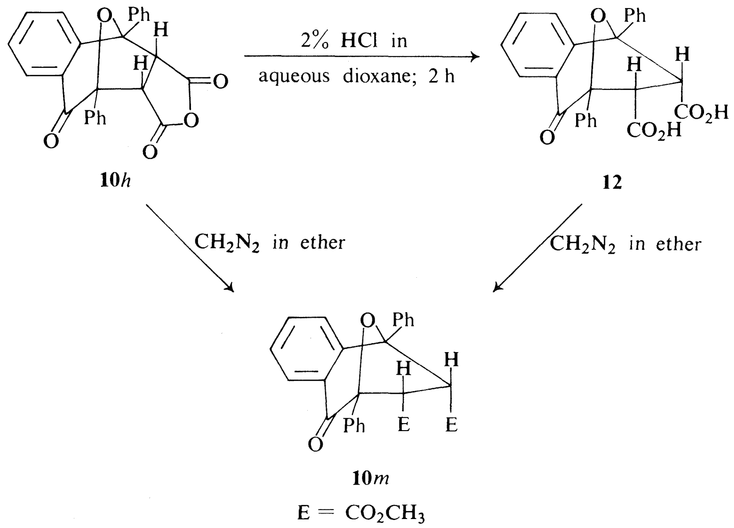
Vinylene carbonate adds to **2** to form adducts in which the ratio of the *endo* to *exo–cis* adducts **9***e* to *f* is 6:1. The indenone oxide similarly affords the *endo* and *exo* adducts **10***f* and *g* in a ratio of 3:1.

Exclusive formation of the endo adducts of **1** was observed with maleic anhydride **10***h* and with *N*-phenylmaleimide **10***i*.

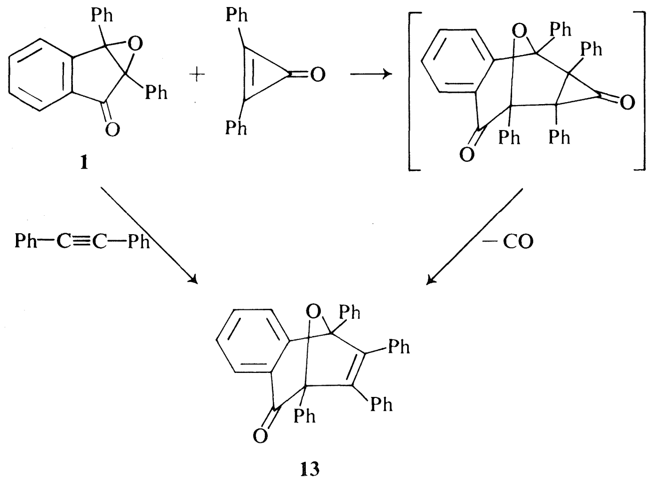
In the addition of **1** to dimethyl maleate and dimethyl fumarate all four possible stereoisomeric adducts were observed allowing a closer comparison of chemical shifts, coupling constants, and the steric requirements of the cycloadditions. With dimethyl fumarate for example two isomeric adducts **10***j* and *k* were obtained in a ratio of 3:1 and assigned by comparison with the single adduct **9***h* of unambiguous structure obtained from **2**. Similarly two isomeric adducts **10***l* and *m* in the proportion of 3.6:1 were obtained by reaction of **1** with dimethyl maleate.

The assignments of **10***l* and *m* were proven by mild acid hydrolysis of the *endo*-maleic anhydride adduct **10***h* to the *cis-endo*-diacid **12** (see Scheme 1). A single diacid was obtained indicating that epimerization had not occurred. Treatment of **12** with diazomethane in ether gave **10***m* in quantitative yield. Direct reaction of diazomethane in ether on **10***h* also gave **10***m* in quantitative yield.

trans-Stilbene afforded two isomeric adducts **10***n* and *o* in the ratio of 5:2. Similarly *trans*-1,2-dicyanoethylene gave rise to two isomeric adducts **10***p* and *q* in the ratio of 7:1 in which assignments were made by comparison with the



SCHEME 1

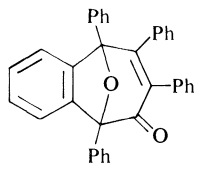


SCHEME 2

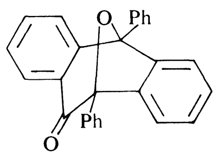
adduct **9***j* obtained from **1**. With very bulky groups like benzoyl on the addend one observes exclusive formation of the 2-*exo*-3-*endo* isomer as in **10***r* obtained from *trans*-dibenzoylethylene. *cis*-Stilbene gives rise to mixtures of *endo* and *exo* adducts **10***s* and *t* in the ratio of 2:3.

A result which parallels observations made with the indanoaziridine **6** (38) was that although commercial crotonitrile consists of a *cis–trans* mixture, reaction with both **1** and **2** gave exclusively *endo* adducts **10***u* and **9***l* respectively, corresponding only to addition of the *cis*-isomer in an *endo* direction. Comparison of the proton–proton coupling with those in the ABC analysis of the methine protons in the adduct **10***v* obtained from acrylonitrile, confirm the *cis* assignments in **10***u* and **9***l*.

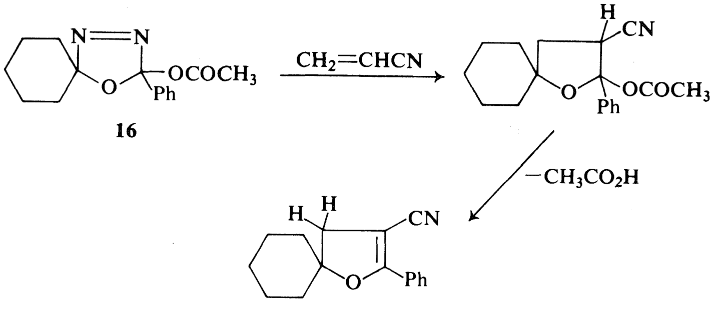
In the reaction of **1** with diphenylcyclopro-



14



15



16

17

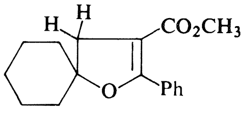
SCHEME 3

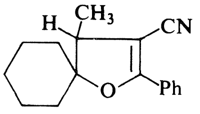
penone (see Scheme 2), cycloaddition of the carbonyl ylide takes place to the carbon–carbon double bond. Subsequent spontaneous loss of the carbon monoxide from the intermediate produces **13** which is also obtained directly with diphenylacetylene. The behavior of diphenylcyclopropenone towards **2** is quite different and involves instead initial attack at the carbonyl bond to form **14** (39).

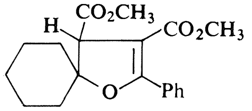
Species **4** can also be trapped with the reactive "acetylenic" dipolarophile benzyne, generated *in situ* from diphenyliodonium-2-carboxylate to give **15**.

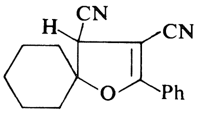
Δ^3-1,3-4-Oxadiazolines provide convenient precursors for acyclic carbonyl ylides. Recently prepared by Hoffman and Luthardt (24) they have been shown by these authors and by Rajagopalan and Advani (23) to cleave at moderate temperatures to carbonyl ylides which may be trapped by acetylenic dipolarophiles.

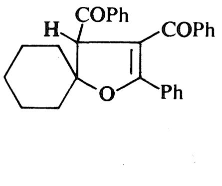
2-Acetyl-5,5-pentamethylene-Δ^3-1,3,4-oxadiazoline (**16**) reacted with acrylonitrile regiospecifically to give a single product **17** (see Scheme 3). In common with the experience of other workers (23, 24) acetic acid was eliminated from the initial product of cycloaddition. The single orientation represented by **17** was proven by the absence of a vinylic absorption in the n.m.r. spectrum. The identical regiospecificity of addition was exhibited in the cycloaddition of **16** to methyl acrylate and to crotonitrile to give **18** and **19** respectively as the only products. The orientation of addition is obvious from the n.m.r. spectra, that of **18** shows a two proton singlet at δ 2.83, and that of **19** shows a methyl group doublet at δ 1.20. Identical products **20** are obtained from both dimethyl maleate and dimethyl fumarate, corresponding to the elimination of acetic acid. Fumaronitrile affords a single adduct **21** in good yield in which acetic acid has also been eliminated during the reaction. Dibenzoylethylene reacted with **16** to give adduct **22**. The previously suggested intermediate (23) in the 1,3-dipolar cycloadditions of olefinic dipolarophiles to carbonyl ylides of this type was isolated in the case of 1,4-naphthoquinone as adduct **23**.

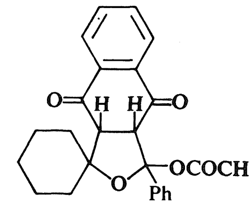

18


19


20


21


22


23

Discussion

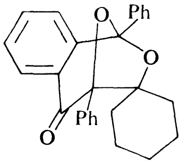
Numerous attempts have been made to account for the Alder *endo* addition rule (40) in the Diels–Alder reaction. Recently the rule has been reinterpreted in quantum mechanical terms by Hoffmann and Woodward who note that the *endo* transition state is stabilized relative to the *exo* transition state by symmetry controlled secondary orbital interaction (41). This view was supported by Herndon and Hall with extended Hückel calculations (42) but more recently these authors have concluded that such secondary orbital interactions may be relatively unimportant and that geometrical overlap relationships of the π-orbitals at only the primary bonding center need be considered (43). Other interpretations have been made in terms of inductive forces (44), charge-transfer interactions (45), and dipole–dipole interactions (46).

While the related $(4 + 2)\pi$ 1,3-dipolar cycloaddition reaction might be expected to involve similar secondary effects leading to preferential *endo* addition, no systematic study has been undertaken. Woller and Cromwell have reported one example of cycloaddition to an aziridine, the direction of which appears to be dictated by maximum overlap of the π-orbitals of the two components (47).

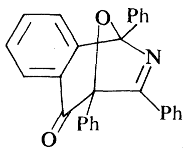
Orientation phenomena in 1,3-dipolar cycloadditions reactions have been interpreted as an interplay of steric and electronic factors (48). Examination of the stereochemistry of addition of symmetrical dipolarophiles to the indenone oxide should minimize electronic factors. The stereospecificity observed in such additions noted above is in agreement with recent conclusions derived from intramolecular isotope effects on the concerted nature of 1,3-dipolar cycloadditions of tetracyanoethylene oxide to allenes (25). Two tendencies are apparent from the above results. First a general preference under these conditions for *endo* additions of *cis*-addends to **1** and **2** but exceptions are noted in the case of dimethyl maleate and *cis*-stilbene. This is in agreement with other reported examples in the case of **2** (33). Arnold and Karnischky have recently shown that the carbonyl ylide derived from the thermal cleavage of 5-oxabicyclo[2,1,0]-pentane forms a mixture of *exo* and *endo* adducts with maleonitrile (27). The *endo* preference for **1** is in agreement with the results obtained with the indanoaziridine **6** (32, 38) and removes the apparent discrepancy between the hitherto observed orientation of additions to **1** and **6**.

A second tendency is apparent during the cycloaddition of *trans*-addends to **1** for the two substituents to adopt 2-*exo*-3-*endo* positions. Although the adducts obtained from **1** appear to be configurationally stable under their conditions of preparation, however, until it is demonstrated that the product distribution in these reactions is kinetically controlled (in view of the high temperatures that must be used), any attempts to formulate a general *endo* rule for such 1,3-dipolar cycloadditions is premature.

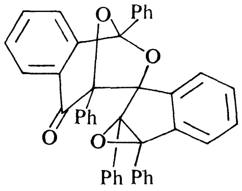
Electronic effects might be expected to play a significant role in determining the regiospecificity of addition of unsymmetrical dipolarophiles to **1** and **2**. Ullmann and Milks have reported in the addition of unsymmetrical addends to **1** a regiospecificity to place the substituents remote from the 1-phenyl group (22) *e.g.* **28**, **29**, **30**.



28



29



30

While steric hindrance factors will contribute here the orientation of all three additions is consonant with electronic directional effects.

Electronic factors may similarly be predominant in producing the regiospecificity observed in the additions to the acyclic ylide derived from **3** *i.e.*., in **17**, **18**, and **19** all of which correspond to the structures expected on the basis of electronic effects.

Experimental

The m.p.'s. were determined with a Fisher–Johns apparatus. The i.r. spectra were recorded with a Perkin–Elmer model 421 spectrophotometer. The n.m.r. spectra were recorded with Varian A-60 and A-100 spectrometers for *ca.* 5–10% (w/v) solutions and were taken on the initially obtained reaction mixtures to obtain an accurate determination of isomeric ratios; line positions are reported in p.p.m. from tetramethylsilane. Mass spectra were determined with an A.E.I. MS12 double-focusing high-resolution mass spectrometer (ionization energy usually 70 eV). Peak measurements were made by comparison with perfluorotributylamine at a resolving power of 15 000. In those cases where mixtures of isomers were obtained, peak measurements were determined on the analytical samples and no attempts were made to separate the isomers. Kieselgel DF-5 (Camag, Switzerland) and Eastman Kodak precoated silica sheets were used for t.l.c. Microanalyses were carried out by Mrs. D. Mahlow of this department.

Preparation of Substrates

2,3-Diphenylindenone oxide and 1,3-diphenylisobenzofuran were prepared by the methods of Weitz and Scheffer (49) and of Newman (50) respectively.

General Procedure for 1,3-Dipolar Cycloadditions

The following experiments are representative of the reaction conditions employed throughout, thereafter the results are summarized in tabular form.

Reaction of 2,3-Diphenylindenone Oxide with Dimethyl Fumarate

A solution of 0.893 g (3 mmol) of 2,3-diphenylindenone oxide and 0.432 g (3 mmol) of dimethyl fumarate in 30 ml of dry toluene was heated to 135° in a sealed tube for 12 h under nitrogen. Evaporation of the solvent *in vacuo* and trituration of the residue with 95% ethanol afforded a mixture of adducts **10***k* and *j* in a ratio of (1:3) as shown by the n.m.r. spectrum, 1.22 g (92% yield), m.p. 188–189° as colorless crystals (from 95% ethanol).

Anal. Calcd. for $C_{27}H_{22}O_6$ (mol. wt. 442.1416): C, 73.3; H, 5.0. Found (442.1410 (mass spectrum)): C, 73.25; H, 5.0.

The i.r., spectrum ν_{max} ($CHCl_3$) 1734, 1705 cm^{-1} (C=O). The n.m.r. spectrum δ_{TMS} ($CDCl_3$) 3.20; 3.39 (4.5H, s, CO_2CH_3 (**10***j*)); 3.32, 3.59 (1.5H, s, CO_2CH_3 (**10***k*)); 4.03, 4.19 (0.5H, ABq, J = 4 Hz (**10***k*) methines); 4.04, 4.57 (1.50H, ABq, J = 5.5 Hz (**10***j*) methines); 6.8–8.3 (14H, m, aromatic protons).

Reaction of 2,3-Diphenylindenone Oxide with Dimethyl Maleate

A solution of 0.596 g (2 mmol) of 2,3-diphenylindenone oxide and 0.576 g (4 mmol) of dimethyl maleate in 25 ml of dry toluene was heated at 135° for 48 h in a sealed tube under nitrogen. Evaporation of the solvent *in vacuo* and trituration of the residue with 50% ethanol afforded a mixture of adducts **10***l* and *m* in the ratio of (3.6:1) as shown by the n.m.r. spectrum 0.82 g (94% yield), m.p. 155–158° as colorless crystals (from 50% aqueous ethanol).

Anal. Calcd. for $C_{27}H_{22}O_6$: (mol. wt. 442.1416): C, 73.3; H, 5.0. Found (442.1409 (mass spectrum)): C, 73.2; H, 4.9.

The i.r. spectrum ν_{max} ($CHCl_3$) 1745, 1714 cm^{-1} (C=O). The n.m.r. spectrum δ_{TMS} ($CDCl_3$) 3.27, 3.40 (4.68 H, s, CO_2CH_3(**10***l*)); 3.50, 3.59 (1.29H, s, CO_2CH_3 (**10***m*)); 3.84, 3.96 (1.56H, ABq, J = 9 Hz, (**10***l*) methines); 4.13, 4.31 (0.43H, ABq, J = 11.5 Hz (**10***m*) methines); 6.8–8.3 (14H, m, aromatic protons).

Reaction of 2,3-Diphenylindenone Oxide with cis-Dichloroethylene

A solution of 0.596 g (2 mmol) of 2,3-diphenylindenone oxide and 15 ml of *cis*-1,2-dichloroethylene in 15 ml of dry toluene was heated to 135° for 12 h under nitrogen. Evaporation of the solvent and excess of dichloroethylene *in vacuo* and trituration of the residue with 95% ethanol afforded **10***a* 0.566 g (72% yield), m.p. 129–131° as colorless crystals; δ ($CDCl_3$) 4.88, 5.05 (2H, ABq, J = 9 Hz, methines). Recrystallization of **10***a* from 95% ethanol or chromatography on alumina afforded the dehydrochlorinated product **11**, m.p. 130–131°, as a pale yellow crystalline solid (from 95% ethanol) in quantitative yield.

Anal. Calcd. for $C_{23}H_{15}O_2{}^{35}Cl$ (mol. wt. 359.0842): C, 77.0; H, 4.2; Cl, 9.8. Found (359.0842 (mass spectrum)): C, 77.4; H, 4.4; Cl, 9.3.

The i.r. spectrum ν_{max} ($CHCl_3$) 1710 cm^{-1} (C=O).

Reaction of 1,3-Diphenylisobenzofuran with cis-1,2-Dichloroethylene

A solution of 1.08 g (4 mmol) of 1,3-diphenylisobenzofuran and 15 ml of *cis*-1,2-dichloroethylene in 15 ml of dry benzene was heated under reflux at 100° for 12 h. Evaporation of the solvent and excess of dichloroethylene *in vacuo* and trituration of the residue with 95% ethanol afforded **9***a* 1.06 g (73% yield), m.p. 138–140°, as colorless crystals (from ether – 95% ethanol).

Anal. Calcd. for $C_{22}H_{16}O^{35}Cl_2$ (mol. wt. 366.0579): C, 71.95; H, 4.4; Cl, 19.3. Found (366.0570 (mass spectrum)): C, 71.8; H, 4.4; Cl, 19.3.

The n.m.r. spectrum δ_{TMS} ($CDCl_3$) 4.90 (2H, s, methines); 7.0–8.1 (14H, m, aromatic protons).

Reaction of 2,3-Diphenylindenone Oxide with Diphenyliodonium-2-carboxylate

A mixture of 0.894 g (3 mmol) of 2,3-diphenylindenone oxide and 2.0 g (6 mmol) of diphenyliodonium-2-carboxylate (51) in 40 ml of *sym*-trimethylbenzene was rapidly raised to reflux temperature and then heated under reflux with stirring for 3 h at which time no remaining 2,3-diphenylindenone oxide could be detected by t.l.c. Evaporation of the filtered solution to remove excess of solvents *in vacuo* gave a yellow oil which was subjected to chromatography on 100 g of alumina. Elution with *n*-pentane removed aromatic by-products, while the main fraction was obtained by elution with benzene, the main portion of which was a pale yellow oil which crystallized from 95% ethanol to give **15**, 0.869 g (80% yield), as a pale yellow solid, m.p. 78–80° (from 95% ethanol).

Anal. Calcd. for $C_{27}H_8O_2$ (mol. wt. 374.1306): C, 86.6; H, 4.85. Found (374.1300 (mass spectrum)): C, 86.7; H, 4.9.

The i.r. spectrum ν_{max} ($CHCl_3$) 1704 cm^{-1} (C=O). The n.m.r. spectrum δ_{TMS} ($CDCl_3$) 6.6–8.2 (m, aromatic protons).

Relation of the Configuration of the Adducts of 2,3-Diphenylindenone Oxide with (a) Maleic Anhydride 10h and (b) Dimethyl Maleate 10m

(*A*) A mixture of 0.04 g (1 mmol) of adduct **10***h* and a 2% solution of hydrochloric acid in 15 ml of 25% aqueous dioxane was heated under reflux gently for 2 h. After cooling the solid which had precipitated was collected representing the diacid **12**, 0.341 g (82% yield), m.p. 150°, which was shown by t.l.c. and n.m.r. to consist of only one isomer.

A solution of 0.2 g (0.5 mmol) of **12** in 20 ml of methanol was treated with a solution of diazomethane prepared from 0.82 g (4 mmol) of *p*-toluenesulfonylmethylnitrosamide (Diazald) and the mixture stirred for 12 h. Removal of the solvents *in vacuo* and recrystallization of the residual solid from aqueous methanol afforded the diester **10***m*, 0.21 g (95% yield), m.p. 160–161°. The

TABLE 1. 1,3-Dipolar cycloaddition adducts of 2,3-diphenylindenone oxide with olefinic dipolarophiles

					Melting point (°C)	Yield (%)	Isomer ratio*	Calculated (%)				Found (%)				Mass spectra	
10	R_1	R_2	R_3	R_4				C	H	N	Cl	C	H	N	Cl	Calculated	Found
b	H	Cl	Cl	H	132	69	17:83	69.8	4.1	—	17.9	69.6	4.2	—	17.6	394.0528($C_{23}H_{16}O_2{}^{35}Cl_2$)	394.0528
c	Cl	H	H	Cl													
d	-[1,8-naphthyl]-		H	H	219	93	62:37	88.0	4.9	—	—	87.3	4.8	—	—	450.1619($C_{33}H_{22}O_2$)	450.1610
e	H	H	-[1,8-naphthyl]-														
f	—OCOO—		H	H	218	87	75:25	75.0	4.1	—	—	74.97	4.19	—	—	384.0998($C_{24}H_{16}O_5$)	384.0990
g	H	H	—OCOO—														
h	—COOCO—		H	H	227	89	100:0	75.8	4.1	—	—	75.75	4.2	—	—	396.0998($C_{25}H_{16}O_5$)	396.0990
i	—CONPhCO—		H	H	261	93	100:0	78.1	4.5	3.00	—	78.1	4.5	2.7	—	471.1471($C_{31}H_{21}O_4N$)	471.1465
j	CO_2CH_3	H	H	CO_2CH_3	188	92	75:25	73.3	5.0	—	—	73.25	5.0	—	—	442.1416($C_{27}H_{22}O_6$)	442.1410
k	H	CO_2CH_3	CO_2CH_3	H													
l	H	H	CO_2CH_3	CO_2CH_3	157	94	22:78	73.3	5.0	—	—	73.2	4.9	—	—	442.1416($C_{27}H_{22}O_6$)	442.1409
m	CO_3CH_3	CO_2CH_3	H	H													
n	Ph	H	H	Ph	193	93	70:30	87.8	5.5	—	—	88.0	5.5	—	—	478.1933($C_{35}H_{26}N_2O_2$)	478.1930
o	H	Ph	Ph	H													
p	CN	H	H	CN	203	85	87:13	—	—	7.0	—	—	—	7.3	—	376.1213($C_{25}H_{16}N_2O_2$)	376.1207
q	H	CN	CN	H													
r	COPh	H	H	COPh	216	88	100:0	83.1	4.9	—	—	82.8	4.9	—	—	534.1831($C_{37}H_{26}O_4$)	534.1824
s	Ph	Ph	H	H	68	72	40:60	87.8	5.5	—	—	87.9	5.5	—	—	478.1933($C_{35}H_{26}O_2$)	478.1933
t	H	H	Ph	Ph													
u	CN	CH_3	H	H	191	80	100:0	82.2	5.2	3.8	—	82.4	5.3	4.00	—	365.1416($C_{25}H_{19}NO_2$)	365.1410
v	CN	H	H	H	179	98	100:0	82.0	4.9	4.0	—	82.1	4.8	3.75	—	351.1259($C_{24}H_{17}NO_2$)	351.1255
w	—CONPhCO—		H	H	275	93	100:0	75.9	4.3	3.5	—	75.4	4.3	3.3	—	395.1157($C_{25}H_{17}NO_4$)	395.1151

*Determined by integration of n.m.r. spectra.

TABLE 2. Adducts of 1,3-diphenylisobenzofuran

9	R_1	R_2	R_3	R_4	Melting point (°C)	Yield (%)	Isomer ratio*	Calculated (%)				Found (%)				Mass Spectra	
								C	H	N	Cl	C	H	N	Cl	Calculated	Found
a	Cl	Cl	H	H	138	73	100:0	71.95	4.4	—	19.3	71.8	4.4	—	19.3	366.0579($C_{22}H_{16}O^{35}Cl_2$)	366.0570
b	H	Cl	Cl	H	142	73	—	71.95	4.4	—	19.3	71.8	4.5	—	19.4	366.0579($C_{22}H_{16}O^{35}Cl_2$)	366.0576
c	-[1,8-dinaphthyl]-		H	H	† 178	83	75:25										
d	H	H	-[1,8-dinaphthyl]-														
e	—OCOO—		H	H	‡ 218	86	85:15	77.5	4.5	—	—	77.8	4.5	—	—	—	—
f	H	H	—OCOO—														
g	—CONPhCO—		H	H	148	82	100:0	81.25	4.8	3.2	—	81.7	4.8	2.9	—	443.1521($C_{30}H_{21}NO_3$)	443.1515
h	H	CO_2CH_3	CO_2CH_3	H	148	67	—	75.35	5.35	—	—	74.95	5.3	—	—	414.1467($C_{26}H_{22}O_5$)	414.1472
i	CO_2CH_3	CO_2CH_3	H	H	114	76	100:0	75.35	5.35	—	—	75.35	5.35	—	—	414.1467($C_{26}H_{22}O_5$)	414.1472
j	H	CN	CN	H	190	84	—	82.7	4.6	8.0	—	83.0	4.5	7.9	—	348.1262($C_{24}H_{16}N_2O$)	348.1254
k	H	COPh	COPh	H‡	145	86	—	85.35	5.2	—	—	85.4	5.35	—	—		
l	CN	CH_3	H	H	140	67	100:0	85.4	5.7	4.2	—	85.2	5.7	4.1	—	337.1467($C_{24}H_{19}NO$)	337.1455

*Determined by integration of n.m.r. spectra.
†Reference 52.
‡Molecular ion too small for accurate peak measurement.

TABLE 3. Methine and alkyl group chemical shifts and coupling constants for adducts of 2,3-diphenylindenone oxide (**10**) and diphenylisobenzofuran (**9**)

Compound no.	Chemical shifts (δ)				Coupling constants (Hz)				
	R_1	R_2	R_3	R_4	J_{12}	J_{14}	J_{23}	J_{34}	J_{13}
10*a*	—	—	5.05, d	4.88, d				9	
b	4.89, d	—	—	4.95, d		1.5			
c	—	4.72, d	5.08, d	—			4.2		
d	—	—	5.28, d	5.08, d				8.5	
e	4.75, d	4.55, d	—	—	7.5				
f	—	—	5.57, d	5.37, d				8.5	
g	5.46, d	5.36, d	—	—	6.6				
h	—	—	4.49, d	4.35, d				10	
i	—	—	4.38, d	4.23, d				10	
j	3.39*	4.04, d	4.57, d	3.20*			5.5		
k	4.03, d	3.59*	3.32*	4.19, d		4			
l	3.96, d	3.84, d	3.27*	3.40*	9				
m	3.50*	3.59*	4.31, d	4.13, d				11.5	
n	—	3.76, d	4.16, d	—			8.5		
o	3.94, d	—	—	4.07, d		6			
p	—	3.93, d	4.18, d	—			6.5		
q	4.07, d	—	—	4.07, d					
r	—	4.75, d	5.65, d	—			7.5		
s	—	—	4.73, d	4.48, d				12.5	
t	4.48, d	4.16, d	—	—	8.8				
u	—	1.30†	4.04, d	3.2, d				11	
v	—	—	—	—		4		10	11.5
9*a*	—	—	4.90, s	4.90, s					
b	4.42, d	—	—	4.86, d		2.5			
c	—	—	5.12, s	5.12, s					
d	4.35, d	4.35, d	—	—					
e	—	—	5.26, s	5.26, s					
f	5.13, s	5.13, s	—	—					
g	—	—	4.18, s	4.18, s					
h	3.59, d	3.49*	3.30*	4.31, d		4.5			
i	3.49*	3.49*	4.13, d	4.13, d					
j	3.49, d	—	—	3.82, d		4.5			
k	4.52, d	—	—	5.11, d		5			
l	—	1.00†	3.72, d	3.0, d				10	

*CO_2CH_3.
†CH_3.

spectral properties of this material were identical with those of the minor component obtained by direct addition of **1** to dimethyl maleate.

(*B*) The identical product was obtained directly by reaction of **10***h* with a solution of diazomethane in ether in 87% yield.

By the above general procedures a series of adducts of **1** and **2** were prepared. Their analytical and spectral data are summarized in Tables 1–3.

Reaction of 2-Acetyl-5,5-pentamethylene-2-phenyl-Δ^3-1,3,4-oxadiazoline with Acrylonitrile

A solution of 1.37 g (5 mmol) of 2-acetyl-5,5-pentamethylene-2-phenyl-Δ^3-1,3,4-oxadiazoline and 10 ml of acrylonitrile in 20 ml of dry benzene was heated under gentle reflux for 6 h. Evaporation of the solvent and excess of acrylonitrile *in vacuo* gave a brown oil which was subjected to chromatography on 90 g of B.D.H. alumina. Elution with benzene first removed epoxide by-product while elution with chloroform gave **17** as a pale brown solid which was purified by recrystallization from petroleum ether (b.p. 40–60°) 0.628 g (53% yield), m.p. 107–110°.

Anal. Calcd. for $C_{16}H_{17}NO$ (mol. wt. 239.1310): N, 5.85. Found 239.1310 (mass spectrum)): N, 5.9.

The i.r. spectrum ν_{max} ($CHCl_3$) 2197 cm^{-1} (CN). The n.m.r. spectrum δ_{TMS} ($CDCl_3$) 1.0–2.4 (10H, m, C_6H_{11}); 3.42 (2H, s, methylene); 7.1–8.2 (5H, m, aromatic hydrogens).

Reaction of 2-Acetyl-5,5-pentamethylene-2-phenyl-Δ^3-1,3,4-oxadiazoline with Dimethyl Fumarate

A solution of 1.37 g (5 mmol) of 2-acetyl-5,5-pentamethylene-2-phenyl-Δ^3-1,3,4-oxadiazoline and 0.729 g (5 mmol) of dimethyl fumarate in 30 ml of dry benzene was heated under gentle reflux for 4 h when the evolution of nitrogen ceased. Evaporation of the solvent *in vacuo* gave a yellow oil which was subjected to chromatography on 90 g of B.D.H. alumina. Elution successively with hexane, hexane/benzene (9:1), and hexane/benzene (4:1) removed a small amount of epoxide by-product. Elution with benzene gave the main fraction **20** as a colorless solid 1.63 g (73% yield), m.p. 70° (from ether–pentane).

Anal. Calcd. for $C_{19}H_{22}O_5$ (mol. wt. 330.1467): C, 69.1; H, 6.7. Found (330.1460 (mass spectrum)): C, 69.3; H, 6.6.

The i.r. spectrum ν_{max} ($CHCl_3$) 1700 (br) (C=O). The n.m.r. spectrum δ_{TMS} ($CDCl_3$) 1.0–2.4 (10H, m, C_6H_{11}); 3.63, 3.72 (3H each, s, CO_2CH_3), 7.2–8.0 (5H, m, aromatic protons).

TABLE 4. 1,3-Dipolar cycloadditon products of 2-acetyl-5,5-pentamethylene-2-phenyl-Δ^3-1,3,4-oxadiazoline with olefinic dipolarophiles

Compound no.	R_1	R_2	R_3	Melting point (°C)	Yield (%)	Calculated C	Calculated H	Calculated N	Found (%) C	Found (%) H	Found (%) N	Mass spectra Calculated	Mass spectra Found	Nuclear magnetic resonance spectra R_1	Nuclear magnetic resonance spectra R_2	Nuclear magnetic resonance spectra $R_3(\delta)$	Nuclear magnetic resonance spectra J(Hz)
17	CN	H	H	110	53	—	—	5.85	—	—	5.9	239.1310($C_{16}H_{17}NO$)	239.1310			4.05	
18	CO_2CH_3	H	H	oil	65	—	—	—	—	—	—	294.1256($C_{19}H_{18}O_3$)	294.1252	3.69*	2.83	2.83	
19	CN	CH_3	H	oil	43	—	—	—	—	—	—	253.1467($C_{17}H_{19}NO$)	253.1463		1.20, d	2.96,q	7
20	CO_2CH_3	CO_2CH_3	H	70	76	69.1	6.7	—	69.3	6.6	—	330.1467($C_{19}H_{22}O_5$)	330.1460	3.72*	3.63*	3.83	
21	CN	CN	H	115	64	77.25	6.10	10.6	76.9	5.8	10.5	264.1263($C_{17}H_{16}N_2O$)	264.1262			3.94	
22	PhCO	PhCO	H	68	83	74.24	5.98	—	74.06	6.06	—	422.1882($C_{29}H_{26}O_3$)	422.1876			5.13	
24	—CONHCO—		H	200	88	72.1	6.05	4.9	72.05	5.9	5.0	283.1208($C_{17}H_{17}NO_3$)	283.1210			4.05	

*CO_2CH_3.

An identical product was obtained by reaction of 2-acetyl-5,5-pentamethylene-2-phenyl-Δ^3-1,3,4-oxadiazoline with dimethyl maleate.

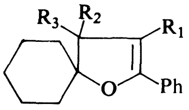
Reaction of 2-Acetyl-5,5-pentamethylene-2-phenyl-Δ^3-1,3,4-oxadiazoline with 1,4-Naphthaquinone

A solution of 1.10 g (4 mmol) of 2-acetyl-5,5-pentamethylene-2-phenyl-Δ^3-1,3,4-oxadiazoline and 0.63 g (4 mmol) of 1,4-naphthaquinone in 40 ml of dry benzene was heated under reflux for 5 h when a dark red solution was obtained. Evaporation of the solvent *in vacuo* gave a dark red oil which was subjected to chromatography on 90 g of B.D.H. alumina. Elution successively with 200 ml of hexane and 300 ml of (3:2) hexane/benzene removed some epoxide by-product and unreacted 1,4-naphthaquinone, while elution with 200 ml of benzene afforded the main fraction. Evaporation of the solvent gave a yellow–green oil, trituration of which with 95% ethanol gave **23** as a pale-green solid 0.63 g (40% yield), m.p. 169–171° (from 95% ethanol).

Anal. Calcd. for $C_{25}H_{24}O_5$ (mol. wt. 404.1624): C, 82.4; H, 6.2. Found (404.1616 (mass spectrum)): C, 82.05; H, 6.5.

The i.r. spectrum ν_{max} ($CHCl_3$) 1672, 1753 cm^{-1} (C=O). The n.m.r. spectrum δ_{TMS} ($CDCl_3$) 1.3–2.4 (10H, m, C_6H_{11}), 1.87 (s, 3H, CH_3); 5.76, 6.65 (2H, ABq, J = 10.5 Hz, methin 6.7–8.2 (9H, m, aromatic protons).

By the above procedures a series of adducts of **16** were prepared. Their analytical and mass spectral data are summarized in Table 4 in which the numbered groups refer to the following structure



This research was supported by the National Research Council of Canada and the Chemistry Department of the University of Alberta.

1. P. B. Woller and N. H. Cromwell. J. Heterocycl. Chem., **5**, 579 (1968).
2. H. W. Heine and R. Peavy. Tetrahedron Lett. 3123 (1965).
3. R. Huisgen, W. Scheer, G. Szeimies, and H. Huber. Tetrahedron Lett. 397 (1966).
4. A. Padwa and L. Hamilton. Tetrahedron Lett. 4363 (1965).
5. H. W. Heine, A. B. Smith, and J. D. Bower. J. Org. Chem. **33**, 1097 (1968).
6. H. W. Heine, R. E. Peavy, and A. J. Durbetaki. J. Org. Chem. **31**, 3924 (1966).
7. A. Padwa and L. Hamilton. J. Heterocycl. Chem. **4**, 118 (1967).
8. A. Padwa and W. Eisenhardt. Chem. Commun. 380 (1968).
9. R. Huisgen, W. Scheer, and H. Huber. J. Am. Chem. Soc. **89**, 1753 (1967).
10. S. Oida and E. Ohki. Chem. Pharm. Bull. Jap. **16**, 764 (1968).
11. H. W. Heine and R. P. Henzel. J. Org. Chem. **34**, 171 (1969).
12. J. W. Lown, G. Dallas, and T. W. Maloney. Can. J. Chem. **47**, 3557 (1969).
13. J. W. Lown, J. P. Moser, and R. Westwood. Can. J. Chem. **47**, 4335 (1969).
14. J. W. Lown, R. K. Smalley, and G. Dallas. Chem. Commun. 1543 (1968).
15. J. W. Lown, R. K. Smalley, G. Dallas, and T. W. Maloney. Can. J. Chem. **48**, 89 (1970).
16. G. Dallas, J. W. Lown, and J. P. Moser. J. Chem. Soc. 2383 (1970).
17. J. W. Lown and J. P. Moser. Can. J. Chem. **48**, 2227 (1970).
18. J. W. Lown and K. Matsumoto. Can. J. Chem. **48**, 3399 (1970).
19. W. J. Linn and R. E. Benson. J. Am. Chem. Soc. **87**, 3657 (1965).
20. W. J. Linn. J. Am. Chem. Soc. **87**, 3665 (1965).
21. P. Brown and R. C. Cookson. Proc. Chem. Soc. 185, (1964).
22. E. F. Ullmann and J. E. Milks. J. Am. Chem. Soc. **86**, 3814 (1964).
23. P. Rajagopalan and B. G. Advani. Tetrahedron Lett. 2689 (1967).
24. R. W. Hoffmann and H. J. Luthardt. Chem. Ber. **101**, 3851 (1968).
25. W. R. Dolbier and S. H. Dai. Tetrahedron Lett. 4645 (1970).
26. Thap Do-Minh, A. M. Trozzolo, and G. W. Griffin. J. Am. Chem. Soc. **92**, 1402 (1970).
27. D. R. Arnold and L. A. Karnischky. J. Am. Chem. Soc. **92**, 1404 (1970).
28. R. Huisgen. Angew. Chem. Int. Ed. Engl. **2**, 591 (1963).
29. J. M. Dunston and P. Yates. Tetrahedron Lett. 505 (1964).
30. R. B. Woodward and R. Hoffmann. The conservation of orbital symmetry. Academic Press, New York, N.Y., 1970. p. 87.
31. A. Hassner. J. Org. Chem. **33**, 2684 (1968).
32. J. W. Lown and K. Matsumoto. Chem. Commun. 692 (1970).
33. B. M. Trost. J. Am. Chem. Soc. **91**, 918 (1969).
34. M. A. Battiste and C. T. Sprouse. Tetrahedron Lett. 4661 (1970).
35. M. P. Cava and F. M. Scheel. J. Org. Chem. **32**, 1304 (1967).
36. R. Breslow, G. Ryan, and J. T. Groves. J. Am. Chem. Soc. **92**, 988 (1970).
37. (*a*) K. B. Wiberg and W. J. Bartley. J. Am. Chem. Soc. **82**, 6375 (1960). (*b*) M. A. Battiste. Tetrahedron Lett. 3795 (1964). (*c*) G. L. Closs, L. E. Closs, and W. A. Boll. J. Am. Chem. Soc. **85**, 3796 (1963). (*d*) M. A. Battiste. J. Am. Chem. Soc. **85**, 2175 (1963). (*e*) D. C. F. Law and S. W. Tobey. J. Am. Chem. Soc. **90**, 2376 (1968).
38. J. W. Lown and K. Matsumoto. J. Org. Chem. **36**, 1405 (1971).
39. J. W. Lown, T. W. Maloney, and G. Dallas. Can. J. Chem. **48**, 554 (1970).
40. K. Alder and G. Stein. Angew. Chem. **50**, 510 (1937).
41. R. Hoffmann and R. B. Woodward. J. Am. Chem. Soc. **87**, 4388 (1965).
42. W. C. Herndon and L. H. Hall. Theoret. Chim. Acta, **7**, 4 (1967).
43. W. C. Herndon and L. H. Hall. Tetrahedron Lett. 3095 (1967).

44. (*a*) A. WASSERMANN. Diels–Alder reactions. Elsevier Publishing Co., New York, N.Y., 1965. (*b*) A. WASSERMANN. J. Chem. Soc. 828, 1511 (1935); 432 (1936).
45. R. W. WOODWARD and H. BAER. J. Am. Chem. Soc. **66**, 645 (1944).
46. J. A. BERSON, A. REMANICK, and W. A. MUELLER J. Am. Chem. Soc. **82**, 5501 (1960).
47. P. W. WOLLER and N. H. CROMWELL. J. Org. Chem. **35**, 888 (1970).
48. (*a*) R. HUISGEN. Angew. Chem. Int. Ed. Engl. **2**, 565 (1963). (*b*) R. HUISGEN. J. Org. Chem. **33**, 2291 (1968).
49. E. WEITZ and A. SCHEFFER. Chem. Ber. **54**, 2327 (1921).
50. M. S. NEWMAN. J. Org. Chem. **26**, 2630 (1961).
51. F. M. BERINGER and S. J. HUANG. J. Org. Chem. **29**, 445 (1964).
52. E. BERGMAN. J. Am. Chem. Soc. **74**, 1075 (1952).