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SELECTIVITIES IN 1,2,3-TRIAZOLIDE DISPLACEMENTS OF HALIDES AND ADDITIONS TO ALKYNES[a]

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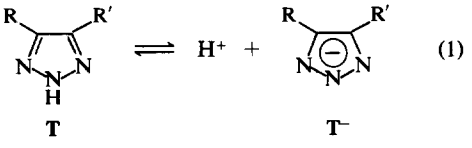
Abstract—4,5-Dicarbomethoxy-1,2,3-triazolide or 4-phenyl-1,2,3-triazolide displace chloride from ethyl chloroacetate or β-chloropropionate to give both 1-N and 2-N alkylated products. Our highest 2-N to 1-N selectivity was *ca* 5/1 and was found with the base triethylamine in DMF. The same triazolides and others add to alkynes, e.g. ethyl propiolate, methyl acetylenedicarboxylate, phenylpropiolaldehyde, ethyl phenylpropiolate, etc, to give Michael adducts at the 2-N position exclusively. Here the usual preference holds, i.e., the *anti* adduct is favored, but *anti* to *syn* isomerization usually sets in. On the basis of the available data for nucleophilic substitutions and additions, a limited directioselectivity pattern emerges for H-1,2,3-triazoles (T) and their anions (T^-): neutral T almost invariably leads with 1-N; T^- usually adds to unsaturates at 2-N; unsubstituted, 4-substituted and 4,5-disubstituted T^- attack organic halides at both 1-N and 2-N. Compared to phenyl, 2-triazolyl exerts a greater deshielding effect on proton chemical shifts; these and other patterns in the PMR spectra of the Michael adducts are discussed. CNDO calculations indicate that the 1-H is more stable than the 2-H-1,2,3-triazole and that in both neutral triazole and in triazolide, the 1-nitrogen position should lead nucleophilic attacks—this directioselectivity prediction is only partly (and probably fortuitously) correct.

Triazolide (T^-), the anion derived from an H-1,2,3-triazole (T), is a species with five potential nucleophilic sites (Eq. 1). Because the pK's are in the same range as those of carboxylic acids,[1] T is readily converted to T^-. As might be anticipated



T T^- (1)

from other systems, the nitrogens of the hetero ring spearhead nucleophilic attacks, although attacks at carbon are also possible.[2] Which attacking nitrogen site is favored, that is the orientation selectivity ("directioselectivity" or "regioselectivity")[3] of T^-, is the broad subject of this paper. A number of groups have looked into this problem, but the general emphasis has been mostly on the synthetic and identification problems, and no generally successful explanations of the preferred orientations are available. Two reactions of T^- were investigated here, namely substitution (Eq. 2) and Michael addition to alkynes (Eq. 3). Having the selectivity results in hand, we wondered whether theory would indicate directioselectivity in this heterocyclic system. Therefore, we carried out CNDO calculations to determine charge densities and energies for several model reactants and products. As a result, we now have an experimental base and a working rationale from which *some* directioselectivity predictions in T^- can safely be made.

RESULTS

Triazolide (T^-) *with organic halides.* The alkylation, arylation, and acylation of H-1,2,3-triazoles are by now familiar reactions.[2] The examples include the parent and simple[4–10] as well as elaborated substrates such as benzotriazoles,[10,11] *vic*-triazolo[1,2-d]naphthalenes,[11] *vic*-triazolo[d]pyrimidines,[12] *vic*-triazolo[4,5-b]pyridines,[13] and 4-aryl-5-triphenylphosphonium-1,2,3-triazole ylids.[14]

Although product assignments have often been based on spectral or other analogies with model compounds,[2,9,15] these are, of course, not infallible indicators of structure. In recent years, however, a number of workers have rigorously established the structures of the products and thus the directioselectivities of Eq. 2. But in some cases the nucleophile(s) involved, that is T, T^-, or both T and T^-, have not always been specified. That the neutral T can and does react is evidenced by the fact that a 1-alkyl-1,2,3-triazole, which is a reasonable analog of T, can be alkylated at the 3-position.[16] To sum-

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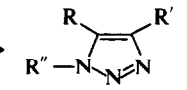
$T^- + R''X$
a: R=R′ = $COOCH_3$
b: R′=Ph, R=H



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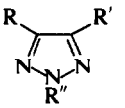


(2)

2a: R=R′ = $COOCH_3$, R″ = $CH_2COOC_2H_5$

b: R′ = Ph, R=H, R″ = $CH_2COOC_2H_5$

c: R=Ph, R′ = H, R″ = $CH_2COOC_2H_5$

d: R′ = Ph, R=H, R″ = $(CH_2)_2COOC_2H_5$

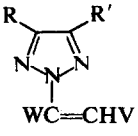
e: R=Ph, R′ = H, R″ = $(CH_2)_2COOC_2H_5$

3a: R=R′ = $COOCH_3$, R″ = $CH_2COOC_2H_5$

b: R=Ph, R′ = H, R″ = $CH_2COOC_2H_5$

c: R=Ph, R′ = H, R″ = $(CH_2)_2COOC_2H_5$

$T^- + WC{\equiv}CV \longrightarrow$



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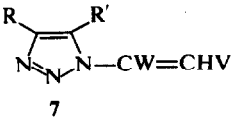

(3)

6a: R=R′ = $COOCH_3$, W=H, V=$COOC_2H_5$

b: R=R′ = W=V=$COOCH_3$

c: R=R′ = $COOCH_3$, W=Ph, V=CHO

d: R=Ph, R′ = W=H, V=$COOC_2H_5$

e: R=W=Ph, R′ = V=$COOC_2H_5$

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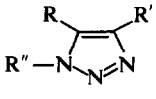
marize the data in this field, we give a number of representative selectivities and their reaction conditions in Table 1.

In this work several triazolides (T^-) were used and elementary facets of alkylation (Eq. 2) were explored. Each T^- led to two products; although a third product (**3b**) is possible from a monosubstituted triazole, none was formed. Since acids derived from the product esters were usually easier to separate and/or identify, the products were often saponified (Eq. 4); we shall regard the structures of corresponding acid and ester as proved when either is established.

Assignments of the structures **2a** and **3a** were made unequivocally on the basis of their PMR spectra. Compounds **2a** and **3a** were confirmed and

2 or 3 $\xrightarrow{OH^-,H_2O}$



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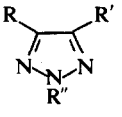

(4)

4

a: R′ = Ph, R = H, R″ = CH_2COOH

b: R = Ph, R′ = H, R″ = CH_2COOH

c: R′ = Ph, R = H, R″ = $(CH_2)_2COOH$

d: R = Ph, R′ = H, R″ = $(CH_2)_2COOH$

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a: R = Ph, R′ = H, R″ = CH_2COOH

b: R = Ph, R′ = H, R″ = $(CH_2)_2COOH$

Table 1. Orientation in the nucleophilic substitution or addition reactions of H-1,2,3-triazoles, 4-R,5-R'-C_2N_3D, or their anions (T^-) with alkyl halides or analogs and unsaturates

T or T^-	Triazole 4-R,5-R	Electrophile( )[a]	Medium[b]	1-N, %[c]	2-N, %[c]	Ref
T	H,H	n-C_3H_7Br (1)	$CH_3O^-Na^+$,CH_3OH	80	20	4
		$(CH_2)_2NH$	neat(?)	(+)	(0)	4
		$(CH_2)_2NH_2^+BF_4^-$	neat	+	0	4
		2,4,6-$(NO_2)_3C_6H_2X$ (9)[d]	various[d]	100	0	5, 7*a*
		2,4,6-$(NO_2)_3C_6H_2F$	DMSO	56(22)	44(78)	5
		2,4-$(NO_2)_2C_6H_3F$	C_2H_5OH	100	0	7*a*
	ArNH,H	2,4,6-$(NO_2)_3C_6H_2F$	DMF	100	0	9*b*
	NO_2,H	2,4,6-$(NO_2)_3C_6H_2F$	DMF	100	0	5
	H,H	H_2C=CHCOOH	neat[e]	100	0	4, 18*a*
		H_2C=$CHNO_2$	$CHCl_3$	100	0	4
T^-Ag^+	H,H	H_2C=$CHCH_2Br$ (1)	C_6H_6	80	20	4
T^-	H,H	$ClCH_2CH_2CN$ (4)	$C_2H_5O^-Na^+$,C_2H_5OH	73	27	4
		$(CH_3)_2SO_4$	HO^-,H_2O	(+)	(+)	6
		4-$O_2NC_6H_4F$	KF	(+)	(+)	7*a*
		2,4,6-$(O_2N)_3C_6H_2F$	$(C_2H_5)_3N$, DMF	0	+	5
		2-$O_2NC_6H_4F$	K_2CO_3, DMF	~ 20	~ 60	7*b*
	O_2N,H	2,4-$(O_2N)_2C_6H_3F$	$(C_2H_5)_3N$, DMSO	(+)	(+)	7*a*
	Ph,H	$ClCH_2COOC_2H_5$	various[f]	+	+	*g*
	Ph,H	$Cl(CH_2)_2COOC_2H_5$	$CH_3O^-Na^+$,DMF	+	+	*g*
	CH_3OOC,$COOCH_3$	$ClCH_2COOC_2H_5$	various[f]	+	+	*g*
	Br,Br	$(CH_3)_2SO_4$	OH^-,H_2O	~ 50	~ 50	8
	$Ph,(C_6H_5)_3P^+$	RX (5)	$CHCl_3$	0	+	14
	—$(CH)_4$—	2,4-$(NO_2)_2C_6H_3F$	$(C_2H_5)_3N$,C_6H_6	98	2	10
			various[h]	~ 67	~ 33	10
	—$(CR)_4$—[j]	$(CH_3)_2SO_4$	OH^-,H_2O	(+)	(+)	11
	H,H	H_2C=CHCN	OH^-,dioxane	0	+	4
	Br,Br	$(CH_3)_2C$=$CHCOCH_3$	R_3N,THF	0	+	8
	R,R'[j]	RC≡CCOR' (10)	$(C_2H_5)_3N$,various[j]	0	+	*f*
	Ar,$(C_6H_5)_3P^+$	HC≡$CCOOC_2H_5$	C_2H_5OH	0	+	14
	—$(CH)_4$—	RCH=CHCOR' (8)	40% Triton B	(+)	(0)	18
	—$(CR)_4$—	CH_3CH=CHCOOH (15)	C_5H_5N	+	+	19

[a] The number of other similar examples is indicated in parentheses.

[b] Complete reaction conditions will be found in the references.

[c] This is the fraction in the product, not the total yield. Where the % is uncertain, we use +; where there is no product we use 0; where the % or + is based on an isolated yield rather than GC or NMR analysis on the product mixture) and this yield is < 60%, we have used parentheses to indicate the uncertainty—one cannot, in general, expect that both isomers are isolable with equal ease.

[d] X=Cl for dioxane, DMF, DMSO; C_6H_6; X=NO_2 for dioxane, DMF, DMSO; X=F for dioxane, DMF.

[e] With or without added pyridine.

[f] Table 2.

[g] This study.

[h] C_2H_5OH, CH_3CN, DMF, DMSO.

[i] Substituents in the 5-, 6-, 7-, and 8- positions of benzotriazole were varied.

[j] Several combinations of reactants in aprotic solvents, e.g., $CHCl_3$, acetone, THF.

3b and **3c** were established independently by their difference from the products of addition of ethyl azidoacetate to the appropriate alkyne (**1**) in Eq. 5.

$$R—C\equiv C—R' + C_2H_5OOC(CH_2)_nN_3 \longrightarrow \mathbf{2} \quad (5)$$

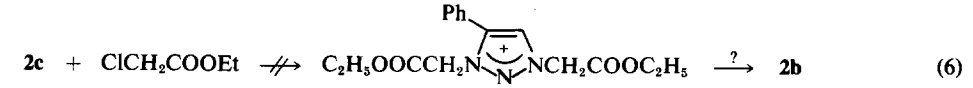
1a($R = R' = COOCH_3$) $n = 1,2$

b($R = C_6H_5$, $R' = H$)

Compound **1a** gave **2a**; **1b** gave **2b** and **2c** but no **3b**; **1b** also gave **2d** and **2e** but no **3c**. At this stage, we are forced to assign the structures of 1- or 3-substituted triazoles on the basis that the chemical shift of the ring proton should be farther downfield, vicinal to (in **4a** δ 8·41 or in **4c** δ 8·31) rather than remote from (in **4b** δ 7·81 or in **4d** δ 7·83) the carboethoxyalkyl substituent. This method of assignment has often been used and proved to be reliable when applied to similar 1,2,3-triazoles of known structure.[4, 14, 17]

Besides process 2, we have obtained **5b** (in several steps) from **1b** and ethyl propiolate (see below) from 4-phenyl-5-triphenylphosphonium-1,2,3-triazole ylid in various ways.[14] The five routes to one or more of the three isomeric triazoles make for an interesting total picture on directioselectivities but do not, however, give us "classical" proofs of the structures of **2d** and **2e**.

To ensure that we were looking at the products of kinetic control, we examined the possibility that equilibration among **2b**, **2c** and **3b** might occur, be it by migration or by group transfer as in Eq. 6.[16]



A solution of **2c**, ethyl chloroacetate, and sodium methoxide in DMF was heated at 75° for 2 days: a PMR spectral check disclosed no change in the initial reactants. Accordingly, we can assume that the first products of process 2 are the ones that we eventually find.

At the outset, it might appear that the selectivity of T^- should be independent of the base which generated it. As can be seen from reactions with ethyl chloroacetate in Table 2, the directioselectivity depends on both the base and the solvent. Incidentally, a selectivity based on analysis of the product solution, e.g. by NMR or GC, is more direct and more accurate than one based on isolated yields. The highest directioselectivity is found in the solvent-base pair of DMF-$(C_2H_5)_3N$. While the ratio of the products of both Ta^- and Tb^- shows sensitivity to the solvent, Ta^- is rather more sensitive to the base than Tb^- is. These effects of substituent and medium indicate to us that ion aggregation and specific intermolecular interactions influence the directioselectivity of T^- attacks. We shall return to this question later.

Triazolide (T^-) *with acetylenic compounds*. The first conjugate additions of **T** or T^- appear to have been made by Wiley, *et al.*, who added benzotriazole to acrylonitrile, cinnamaldehyde, etc., at the 1-nitrogen.[18] Recently, a similar 2-addition of 4,5-dibromo-1,2,3-triazole to mesityl oxide was noted.[8] In these cases, the assignments of the product structures were generally based on their UV spectra. Directioselectivities were more definitive in the additions of H-1,2,3-triazole at the 1-nitrogen to nitroethylene, and at the 2-nitrogen to acrylonitrile,[4] and of numerous mono-, di-, and tetrasubstituted benzotriazoles to crotonic acid,[19] because the products were unequivocally authenticated. When Woerner and Reimlinger added azide ion to methyl propiolate in DMSO, they isolated the expected 4-carbomethoxytriazole (49 or 30% yield) and a methyl β-(4-carbomethoxytriazolyl)-acrylate (0·3 or 0·02% yield).[20] This coproduct, assigned (probably incorrectly) as the 1-triazolyl derivative, seems to be the first published example of process 3. This process was discovered independently by us and is detailed here. Elsewhere, we have also reported on the exclusive formation of the 2-substituted products from 4-aryl-5-triphenylphosphonium-1,2,3-triazole ylids and activated alkynes.[14]

Process 3 poses two orientation problems. The first is the directioselectivity among the triazole nitrogens and the second, which we shall come to shortly, is *anti* versus *syn* addition to the triple bond.[21]

It was quickly apparent that the adducts of 4,5-dicarbomethoxytriazole and alkynes were 2-substituted triazoles. This triazole and ethyl propiolate react in acetone in the presence of triethylamine to give *cis*- and *trans*-**6a**. In the NMR spectrum one can associate a single $COOCH_3$ resonance with each isomer, as is expected for a 2-triazole. By contrast, compounds which can be obtained from dimethyl acetylenedicarboxylate and vinyl azides show two distinct $COOCH_3$ peaks in the NMR spectrum.[17] Indeed, all of our reactions that led to **6a–6c** in Eq. 3 indicated that the 2-nitrogen led the attack, giving none of the 1-N or 3-N adducts. By analogy, the same probably applies to the products **6d** and **6e**, but in the absence of other evidence must be regarded as uncertain. Finally, four other "syntheses" with phenylpropiolaldehyde were carried out on a small scale in NMR tubes and served to support the hypothesis of 2-substitution and to provide tests of an NMR relation to be discussed below (Tables 3 and 4).

Identification of the configuration about the double bond of **6** was essentially based on NMR criteria. In **6a** and **6d** two ethylenic hydrogens are present and the spin coupling constants $J \simeq 10$ and $J \simeq 14$ Hz can reasonably be associated with *cis*- and *trans*- geometry, respectively. Where there is only one ethylenic proton, we resorted to the useful

Table 2. Directioselectivity in the reactions of 4,5-dicarbomethoxy-1,2,3-triazole (**Ta**) and 4-phenyl-1,2,3-triazole (**Tb**) with ethyl chloroacetate

T	Base	Solvent	% 1-N	% 2-N
Ta[a]	CH_3ONa	Ethanol	53	47
	CH_3ONa	DMF	44[b]	56[b]
	DAN[d]	Ethanol	62	38
	DAN[d]	DMF	45[c]	55[c]
Tb[e]	$N(C_2H_5)_3$	C_2H_5OH	43	57
	$N(C_2H_5)_3$	CH_3OH	44	56
	$N(C_2H_5)_3$	THF	30	70
	$N(C_2H_5)_3$	DMF	16, 17	84, 83
	$NaOCH_3$	C_2H_5OH	34	66
	$NaOCH_3$	DMF	28	72
	DAN[d]	DMF	18	82

[a]At 65°. The products were hydrolyzed and determined by NMR.
[b]Combined yield was 56%.
[c]Combined yield 35%.
[d]DAN is 1,8-*bis*-dimethylaminonaphthalene.
[e]75°. The products were analyzed by NMR.

empirical chemical shift correlation:[22]

$$\delta\left(\begin{array}{l} H \\ R_{gem} \end{array}\!\!>\!C\!=\!C\!<\!\!\begin{array}{l} R_{cis} \\ R_{trans} \end{array}\right) = 5{\cdot}25 + Z_{gem} + Z_{cis} + Z_{trans} \quad (7)$$

In this additive relation, the Z values are empirically determined from some model ethylenes and may be used to estimate the δ values in others. Since other Z values were known,[22] the Z value for the 2-triazolyl group (2-**T**) could be evaluated. Using *cis*- and *trans*-**6a**, we estimate $Z_{gem} = 1{\cdot}48$ and $Z_{trans} = -0{\cdot}01$ in *cis*-**6b** and $Z_{gem} = 1{\cdot}61$ and $Z_{cis} = 0{\cdot}69$ in *trans*-**6b**. Using **6c**, we estimate $Z_{trans} = 0{\cdot}02$ and $Z_{cis} = 0{\cdot}95$; the opposite geometry would lead to $Z_{cis} = 0{\cdot}48$ and $Z_{trans} = 0{\cdot}51$, which are not plausible. Similar results were obtained for the other 2-triazolylethylenes (Table 4). Evidently, Z values are slightly solvent sensitive and for the trisubstituted alkenes agree rather better amongst themselves than with values obtained from the disubstituted alkenes (**6a**).

The 2-triazolyl products of process 3 generally consisted of *cis* and *trans*-**6**. By following the appearance of the ethylenic proton peaks in the NMR spectrum, we observed that the *anti* adduct predominates at first. Then, as this form gradually disappears, the *syn*-adduct appears. This behavior is illustrated for **6c** in Table 5 and **6e** in Fig. 1, and is

Table 3. Products of reaction of H-1,2,3-triazoles, R–T–R′, with phenylpropiolaldehyde in the presence of triethylamine. Adducts are *anti* (*a*) and *syn* (*s*)

Products					Products		J_{CHCHO}
6	R	R′	Solvent		$\delta_{(CHO)}$	$\delta_{(=CHCO)}$	Hz
c	CO_2CH_3	CO_2CH_3	$CDCl_3$	*a*	9·69	6·61	7·0
				s	9·52	7·15	7·5
c	CO_2CH_3	CO_2CH_3	Acetone	*a*	9·72	6·73	7·0
				s	9·55	7·02	7·5
f	CHO	C_6H_5	Acetone	*a*	9·92	6·68	7·0
				s	9·62	7·14	7·5
f	CHO	C_6H_5	DMAC	*a*	9·92	6·82	7·0
				s	9·60	7·10	7·5
g	CO_2Et	C_6H_5	Acetone	*a*	9·91	6·61	7·0
				s	9·61	7·11	7·6
h	CO_2Et	*m*-NO_2—C_6H_4	Acetone	*a*	9·91	6·89	6·9
				s	9·63	7·10	7·4
i	CO_2Et	*p*-NO_2—C_6H_4	Acetone	*a*	9·81	6·61	6·9
				s	9·52	7·02	7·6

Table 4. The additive shielding contribution, Z, in ppm of the 2-triazolyl moiety to the chemical shift of the alkene proton in (2-(4-R,5-R′-C_2N_3))CW=CYH (**6**) in Eq. 6[a]

6	4-R,5-R′	*W*	Y	Solvent	Z_{cis}	Z_{trans}	Z_{gem}
a	MeOOC, COOMe	H	COOEt	$CDCl_3$	0·69		1·61
				$CDCl_3$		−0·01	1·48
d	Ph, H	H	COOEt	CCl_4		−0·41[b]	1·37[b]
				$CHCl_3$	0·64		1·79
c	MeOOC, COOMe	Ph	CHO	$CDCl_3$	0·95	−0·02	
				$(CH_3)_2CO$	0·82	0·10	
b	MeOOC, COOMe	MeCOO	COOMe	$(CH_3)_2CO$	(0·42)[c]	−0·12[c]	
f	Ph, CHO	Ph	CHO	$(CH_3)_2CO$	0·94	0·05	
				DMAC	0·90	0·19	
g	Ph, COOEt	Ph	CHO	$(CH_3)_2CO$	0·91	−0·02	
e	Ph, COOEt	Ph	COOEt	$CDCl_3$	1·04[c]	(0·61)[c]	
h	*m*-$O_2NC_6H_4$, COOEt	Ph	CHO	$(CH_3)_2CO$	0·90	0·26	
i	*p*-$O_2NC_6H_4$, COOEt	Ph	CHO	$(CH_3)_2CO$	0·82	−0·02	

[a]The shielding increments of substituents W or V were taken from Ref. 22*a* and listed as Z_{gem}, Z_{cis}, and Z_{trans}: CHO 1·02, 0·95, 1·17; COOR 0·80, 1·18, 0·55; COOR (conjugated) 0·78, 1·01, 0·46; Ph 1·38, 0·36, −0·07. The "conjugated" values are to be used when either the substituent or the double bond is conjugated with other substituents.

[b]*Cis* isomer **6d** from Ref. 14. A methyl ester corresponding to *trans*-**6d**, assigned as a 1-triazolyl adduct in Ref. 20, yields Z_{cis} 0·87 and Z_{gem} 1·87.

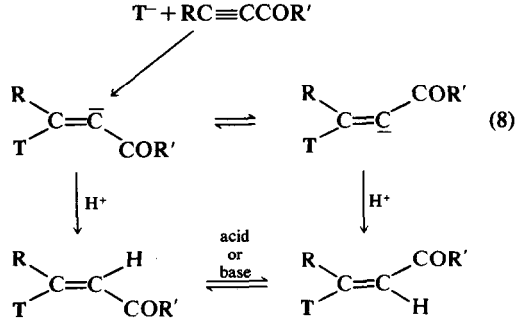
[c]Only one isomer was found. The calculated value which seems less probable is given in parentheses.

Table 5. Product ratio of the reaction of 4,5-dicarbomethoxy-1,2,3-triazole with ethyl propiolate at 25°[a]

Base[b]	Base %[c]	Time, hr	*Anti/syn*
DEA	6	22	1·75
DEA	6	48	1·42
TEA	6	16	0·29
TEA	6	25	0·20
TEA	6	48	0·10
TEA	2	16	0·88

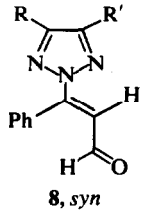
[a]The triazole (0·167 mmol) was dissolved triethylamine-acetone solution (0·50 ml) and ethyl propiolate (0·167 mmol) was added.
[b]DEA, diethylaniline; TEA, triethylamine.
[c]The volume percent of base in the acetone solution is given.

consistent with a generalized mechanism (Eq. 8) which could account both for favored *anti* addition and subsequent isomerization of the products.[21] Admittedly, the rule of favored *anti* addition cannot always be applied unambiguously;[21] in this work, however, assignments of *cis* and *trans* isomers based on the *anti* rule were always in accord with the requirements of Eq. 7.

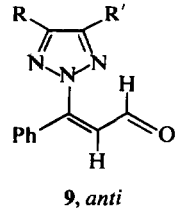


(8)

Relation 7 has produced derived values of Z_{gem} for 2-**T** which should be identical but are not; this gives one an indication of the accuracy to be expected from Eq. 7. Secondly, Z_{gem} and Z_{cis} for 2-**T** exceed those of phenyl, implying that the triazole ring exerts a stronger deshielding effect. This deshielding influence is apparent in the triazole phenylpropiolaldehyde adducts and gives rise to consistent correlations between chemical shift and structure (Table 3). In all of these cases (**8**, **9**), the chemical shift of the aldehydic or alkene proton is



8, *syn*



9, *anti*

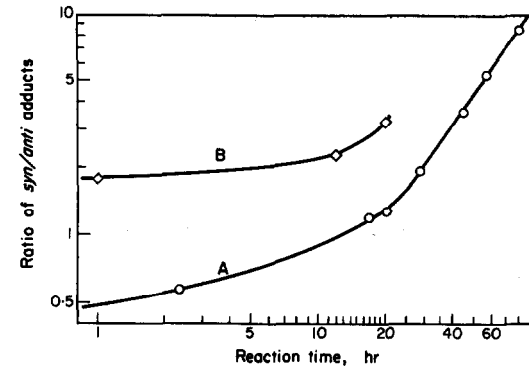


Fig 1. Addition of 4,5-dicarbomethoxy-1,2,3-triazole to phenylpropiolaldehyde in tetrahydrofuran at 60°: A, base, *p*-methoxydiethylaniline (2% by volume); B, base, triethylamine (2% by volume).

farther downfield when it can be closer to the triazole rather than the phenyl ring.

CNDO calculations. Using the Hückel Molecular Orbital,[23] LCAO-SCF,[24] or CNDO[25] approaches, several groups have already made exploratory calculations of the neutral 1-H- and 2-H-1,2,3-triazoles. Our purpose here was to see whether a theoretical investigation of substituted 1,2,3-triazoles and their anions by the CNDO method could shed some light on their properties, particularly the directioselectivity in the reactions of 1,2,3-triazole as nucleophile.

Bond parameters of H-1,2,3-triazoles and triazole anions are largely unknown so that the structures of similar compounds were used as models in our choice of dimensions and geometry.[26] The coordinates for the calculations are shown in Figs 2–8. Wherever possible we used simple models to gauge the effect of complex groups; hydrogen is our usual substituent, the cyano function stands in for a carbonyl or ester group, and vinyl is a model for phenyl. In all, we examined structures **10–17**

Table 6. Total energies of 1,2,3-triazoles and their anions from CNDO calculations

Compound (Figure No.)	Triazole	Total energy (a.u.)
10 (2)	1-H-1,2,3-Triazole	−51·456
		−51·547[a]
11 (3)	2-H-1,2,3-Triazole	−51·448
		−51·540[a]
12 (4)	1,2,3-Triazole anion	−50·605
13 (5)	4-Cyano-1,2,3-triazole anion	−68·432
14 (6)	4-Vinyl-1,2,3-triazole anion	−66·287
15[b]	4-Phosphonium-1,2,3-triazole	−58·999
16 (7)	2N-Triazolylvinyl anion	−66·140
17 (8)	1N-Triazolylvinyl anion	−66·158

[a]Ref 25.
[b]Ref 14.

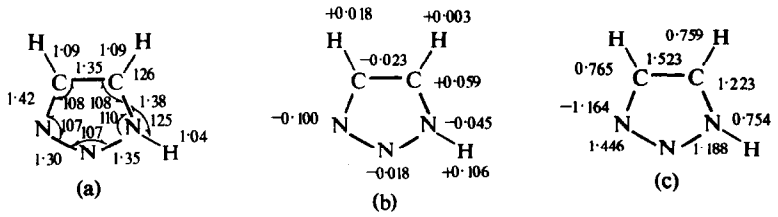


Fig 2. CNDO calculation of 1H-1,2,3-triazole (**10**). (a) Geometry; bond distances, Å, and angles in degrees. (b) Atomic charge densities. (c) Relative bond energies.

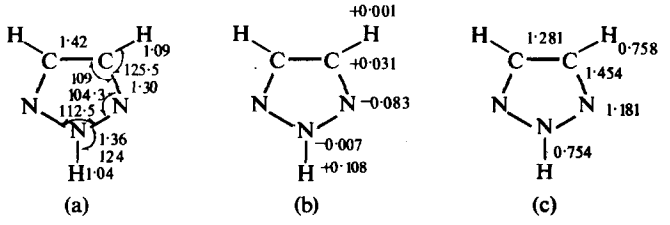


Fig 3. CNDO calculation of 2H-1,2,3-triazole (**11**). (a) Geometry; bond distances, Å, and angles in degrees. (b) Atomic charge densities. (c) Relative bond energies.

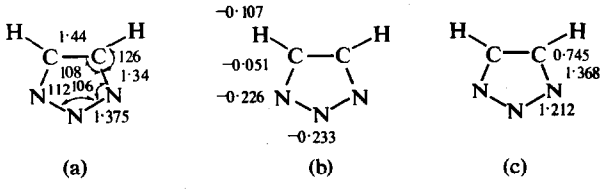


Fig 4. CNDO calculation of 1,2,3-triazole anion (**12**). (a) Geometry; bond distances, Å, and angles in degrees. (b) Atomic charge densities. (c) Relative bond energies.

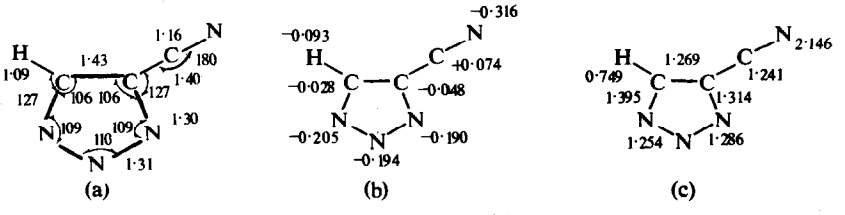


Fig 5. CNDO calculation of 4-cyano-1,2,3-triazole anion (**13**). (a) Geometry; bond distances, Å, and angles in degrees. (b) Atomic charge densities. (c) Relative bond energies.

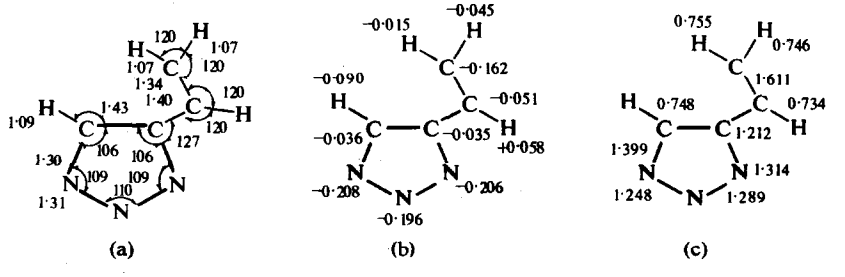


Fig 6. CNDO calculation of 4-vinyl-1,2,3-triazole anion (**14**). (a) Geometry; bond distances, Å, and angles in degrees. (b) Atomic charge densities. (c) Relative bond energies.

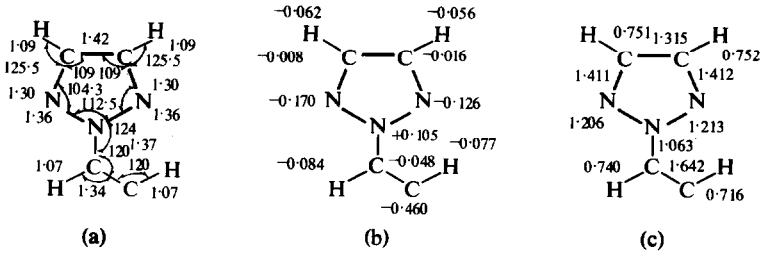


Fig 7. CNDO calculation of 2N-1,2,3-triazolylvinyl anion (**16**). (a) Geometry; bond distances, Å, and angles in degrees. (b) Atomic charge densities. (c) Relative bond energies.

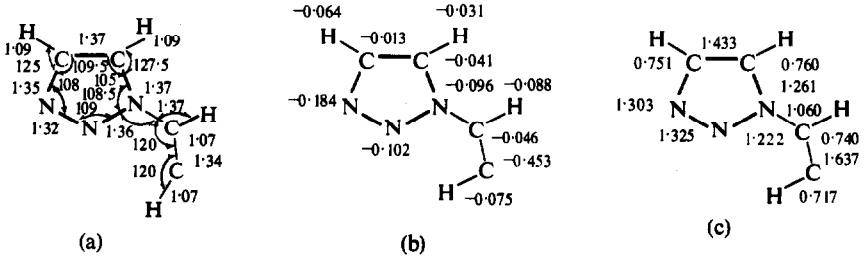


Fig 8. CNDO calculation of 1N-1,2,3-triazolylvinyl anion (**17**). (a) Geometry; bond distances, Å, and angles in degrees. (b) Atomic charge densities. (c) Relative bond energies.

(Table 6 and Figs 2–8). Our emphasis on anions stems from the possible variations in reactants and products involving 1- *versus* 2-N as the nucleophilic point in Eqs. 2 and 3.

The CNDO calculations gave total energy, atomic charge densities, relative bond energies and quantum indices, e.g., exchange energies, coulombic energies and nuclear energies.[27] Relative bond energies correspond to diatomic contributions to the total energy, E_{AB}, as defined by Pople.[27a] Total energies of 1,2,3-triazole and 1,2,3-triazole anions are listed in Table 6. Atomic charge densities, relative bond energies and atom coordinate diagrams are shown in Figs 2–8.

One may get a feel for the relevance of the theoretical calculations as follows. Although our estimated total energies of 1-H and 2-H-1,2,3-triazoles are larger than those of Vaughan and O'Donnell,[25] the differences between these isomers are constant at *ca* 0·008 a.u. (Table 6). These differences may reflect the great sensitivity of total energy to molecular geometry in this method.[27c] The total CNDO energies are such that 1-H appears to be more stable than 2-H-1,2,3-triazole by *ca* 0·008 a.u. (6 kcal). Quite the opposite is indicated by Roche and Pujol, who estimated by the LCAO method that 2H- is more stable than 1-H-1,2,3-triazole by 0·011 a.u. (7 kcal).[24] Experimental observations can be educed on both sides of this issue: an analysis of gas phase IR data favors the 1-N isomer,[28] in accord with the CNDO calculations; but interpretations of ^{1}H-NMR or ^{14}N-NMR of H-1,2,3-triazoles in solution are contradictory and not inconsistent with aggregates involving both forms;[4,28,29] interpretations of the dipole moment of dilute solutions of 1,2,3-triazole in benzene, which have favored the 2-isomer,[2,30] are plausible but not compelling, since self-association is likely to be strong[31] and possible difficulties with the model compounds were not taken into account. For these reasons, we assume that the ratio of 2-H to 1-H-1,2,3-triazoles is medium dependent and sufficiently close to unity so that both forms are accessible.

Whatever the method, all calculations show that the ring nitrogens are usually more negative than the carbon atoms in H-1,2,3-triazoles.[23–25] It is not surprising therefore that these compounds are bases, participate in hydrogen bonding, form metal salts, transalkylate, etc.[2] Since the charge densities on the N atoms are even greater in T^-, this should be at least as powerful a nucleophile as T; certainly, bases which convert T to T^- are frequently employed in conversions such as Eqs. 2 and 3. In this regard, base-catalyzed halogenation of triazoles is "normal" as in the formation of 2-N-chlorobenzotriazole,[32] where the carbon atoms are unavailable, but "abnormal" in the formation of 4- and 4,5-dihalo-1,2,3-triazoles.[6] In the latter case, a check of kinetic *versus* equilibrium control of products might clarify the apparent inversion in nucleophilicities.

Our calculations indicate the following order of electron density at nitrogen (Figs 2–6): in 1-H-**T**, 3- > 1- > 2-; in 2-H-**T**, 3- = 1- > 2-; in 1,2,3-triazole anion, 2- > 1- = 3-; in 4-cyano-1,2,3-triazole anion, 1- > 2- > 3-; in 4-vinyl-1,2,3-triazole anion,

1- ~ 3- > 2. Based on these *ground state* electron densities, one would have to make the general prediction that *nucleophilic attacks should be led by that nitrogen which is most distant from ring substituents in* **T** *or* $\mathbf{T}^-$. Even in the apparent exception of $\mathbf{T}^-$ (Fig 4), the calculated charge densities are probably sufficiently close to allow for both 2-N and 1-N attacks.

We also considered product-like models for the reactions of $\mathbf{T}^-$. The 1- and 2-H-1,2,3-triazoles may be taken as analogs for the substitution (Eq. 2) and the triazolyl-1-N-vinyl and 2-N-vinyl anions (Figs 7, 8) were analogs for the addition (Eq. 3) activated complexes. Again, the CNDO predictions are that the 1-N *rather than the* 2-N *product or "activated complex" is favored.*

To summarize this section, we note that the CNDO calculations give results which agree generally with a gross or qualitative picture of H-1,2,3-triazoles. They are probably less reliable when one wishes to make distinctions among isomeric triazole species. And although the calculations correctly make the 1-N position out to be the most nucleophilic in neutral **T**, we shall argue in the next section that electronic effects contribute only in a minor way to the directioselectivity.

Directioselectivity. By reaching into the bag of "effects" or "factors", it is sometimes possible for the chemist to hold up one which clearly is the most important. In examining the literature on the reactions of **T** and $\mathbf{T}^-$ as nucleophiles (Table 1), we discern most of the usual effects but find it difficult to theorize or predict too far from the data base. Because the available observations usually derive from synthetic work, the reaction conditions cannot be closely defined, but there are several features which stand out: (1) neutral **T** almost always attacks at the 1-N; (2) $\mathbf{T}^-$ (except for benzotriazolides) almost always attacks unsaturates at the 2-N; (3) alkyl halides are usually attacked at 1- and 2-N by un-, 4-, or 4,5- substituted $\mathbf{T}^-$.

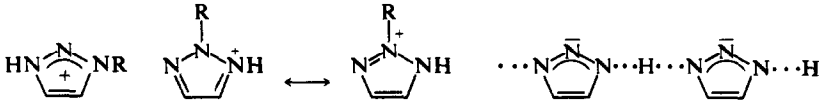
Gold was apparently the first to recognize differences between **T** and $\mathbf{T}^-$ as nucleophiles and to stress the energetic advantage of forms such as **18** over **19**.[4] This provides a rationale for the 1-N orientation of neutral **T** in forming the activated complex. The reaction of picryl fluoride with H-1,2,3-triazole, for example, in DMF gives the 1-N isomer in the absence of base and the 2-N isomer in the presence of base.[5] Likewise, in those reactions in which an acid is present or produced, e.g. the addition of H-1,2,3-triazole to acrylic acid in the presence or absence of pyridine,[4] or in the reactions of **T** or $\mathbf{T}^-$ with an alkyl halide in the presence of catalytic rather than stoichiometric quantities of base, 1-N attack is usually found (Table 1).

Some of Gold's other explanations of directioselectivity do not stand up.[4] He suggested, for example, that the hydrogen-bonded aggregate **20**, which he believed to represent the usual state of *H-1,2,3*-triazole in solution, would lead to an exposed and therefore a more nucleophilic 2-N. Since proton transfers among all three nitrogens on the triazole are relatively rapid, ground state differences cannot be used to rationalize the selectivity of products formed in rate-determining steps. For the same reasons, it is immaterial whether monomeric 1-H or 2-H-1,2,3-triazole is the dominant species in the reactants. At any rate, the fact is that neutral **T**, aggregated or not, generally leads to 1-N substitution.

One regular feature of the substitution reactions of $\mathbf{T}^-$ has been pointed out, namely the steric effect of a 4-substituent.[8,9] Thus, a single 4-substituent, e.g., nitro, phenyl, or anilino, directs attack to the 1- and 2-N positions (Table 1). With "large" 4- and 5-substituents, e.g., aryl, triphenylphosphonium, attack occurs only at 2-N.[14] With two "smaller" substituents, e.g. hydrogen, bromine, carbomethoxy, or a fused ring (in benzotriazolide), all three nitrogens are attack points (Table 1). For reasons which are not entirely clear, many of the addition reactions of $\mathbf{T}^-$ are further restricted to 2-N so that additional factors seem to be superimposed on the steric factor. Obviously, directioselectivities also depend on the electrophile.

Two further effects in directioselectivity are in evidence but it is difficult to estimate their importance in a given system. We believe that electronic effects are generally small, since 4-, 5-, 6-, or 7-substituents, e.g., CH_3, Cl, NO_2, and CF_3 in benzotriazole, lead to both 1- and 2-N attack in Eqs. 2 or 3.[11,19] Secondly, the effects of changing solvent, at least among polar solvents, are visible but rarely overwhelming (Tables 1, 2). An instructive example is given by Wilshire who reported that the 1-N to 2-N product ratio in the reactions of benzotriazolide with an aryl fluoride changes from *ca* 2/1 in ethanol, acetonitrile, DMF and DMSO to 49/1 in benzene.[10] It is evident that both base and solvent, and possibly ion aggregation with polydent $\mathbf{T}^-$ in solvents of low polarity,[33] can and do change directioselectivities.

Perhaps it was overly optimistic to expect that one could account for directioselectivities in the reactions of 1,2,3-triazoles as nucleophiles. For research workers who collected synthetic examples



18 **19** **20**

of Eqs. 2 and 3, this certainly was a secondary objective at best. But directioselectivity is not a trivial or a localized issue: it emerges in other five-atom heterocyclics, e.g., oxazole-5-ones, 1,2,4-triazoles, pyrazoles, tetrazoles, etc.[34] What is needed now for triazoles and, indeed, for all of these heterocyclics, are studies in which the effects of base, solvent, substituents, electrophiles, etc., are carefully evaluated and patterns established so that one can at least rely on experimental observation, if not on theory.

EXPERIMENTAL

H-1,2,3-triazoles were available from previous work.[1,14] PMR spectra were obtained on a Varian A-60 instrument. Chemical shifts, in ppm relative to internal TMS, are estimated to be precise to ±0·5 Hz; s,d,t,m are used to indicate singlet, doublet, triplet, multiplet, respectively. Infrared spectra were recorded on a Beckman IR-8-Spectrometer. All m.ps were taken in capillary tubes on a Mel-Temp Instrument and are uncorrected. Microanalyses were performed by M-H-W Laboratories, Garden City, Michigan.

Ethyl(4,5-*dicarbomethoxy*-1,2,3-*triazol*-1-yl) (**2a**) *and ethyl*(4,5-*dicarbomethoxy*-1,2,3-*triazol*-2-yl)*acetates* (**3a**). A soln of 4,5-dicarbomethoxy-1,2,3-triazole (0·132 g, 0·713 mmol), ethyl chloroacetate (0·140 g, 1·15 mmol) and NaOEt (0·050 g, 0·925 mmol) in EtOH (5 ml) was heated at reflux for 1 day, cooled, and worked up with ether and water. From the ether, an oily residue was obtained, which when chromatographed on silica gel with benzene, ether, and MeOH, yielded two isomers. An early eluate gave **3a** (0·10 g, 52%) which had: m.p. 62–63°; NMR (acetone) δ 1·24 (t, 7·1 Hz, 3H), 3·92 (s, 6H), 4·25 (q, 7·1 Hz, 2H), 5·49 (s, 2H); IR ($CHCl_3$) 1770–1740, 1469, 1443, 1379, 1349, 1230–1200 cm^{-1}. (Found: C, 44·24; H, 4·88. Calcd. for $C_{10}H_{13}N_3O_3$: C, 44·28; H, 4·83%).

Later eluates gave **2a** (0·056 g, 29%), m.p. 121–122°, which was identical with a sample prepared another way (see below).

For the purpose of observing the ratio of the 2- to the 1-substituted triazoles, the following procedure was followed. An NMR tube was charged with a solution of dicarbomethoxy-1,2,3-triazole (31 mg, 0·17 mmol), ethyl chloroacetate (21 mg, 0·17 mmol), an equimolar amount of base (Et_3N, NaOEt, or *bis*-1,8-dimethylaminonaphthalene and solvent (alcohol or DMF). The soln was kept at 65° for 15 hr, then evaporated to remove volatile materials. The residue was dissolved in acetone (0·4 ml), the δ's for the methylene groups in the NMR spectra were measured, and the peak areas were integrated. Our data are collected in Table 2.

Ethyl(4, 5-*dicarbomethoxy*-1, 2, 3-*triazol*-1-y1)*acetate* (**2a**). A soln of dimethyl acetylenedicarboxylate (7·1 g, 0·05 mol) and ethyl azidoacetate (6·5 g, 0·05 mol) in toluene (20 ml) was heated at reflux for 3 days and cooled. The white solid which deposited was filtered, washed with toluene, and recrystallized from toluene (12·4 g, 91%): m.p. 122–123°; NMR (acetone) δ 1·25 (t, 7·1 Hz, 3H), 3·93 (s, 3H), 3·95 (s, 3H), 4·27 (q, 7·1 Hz, 2H), 5·58 (s, 2H); IR ($CHCl_3$) 2998, 2952, 1770–1740, 1575 cm^{-1}. (Found: C, 44·28; H, 4·90. Calcd for $C_{10}H_{13}N_3O_3$: C, 44·28; H, 4·83%).

Ethyl(4-*phenyl*-1,2,3-*triazol*-1-yl) (**2b**) *and* (5-*phenyl*-1,2,3-*triazol*-1-yl) (**2c**) *acetates*. A soln of freshly distilled phenylacetylene (10·2 g, 0·1 mol) and ethyl azidoacetate (12·9 g, 0·1 mol) in toluene (25 ml) was heated at reflux for 2 days and evaporated to remove the solvent. The solid residue was dissolved in hot EtOH and filtered through charcoal; upon cooling, the filtrate deposited **2b** (6·05 g, 26%): m.p. 94–95° (lit.[35] 97–98·5°); NMR (acetone) δ 1·23 (t, 7·1 Hz, 3H), 4·23 (q, 7·1 Hz, 2H), 5·39 (s, 2H), 7·45 (m, 3H), 7·95 (m, 2H), 8·46 (s, 1H); IR ($CHCl_3$) 1754 cm^{-1}. The filtrate was concentrated to give a solid (13 g), which did not crystallize, but did give more **2b** on further workup (see below). A part of the residue (1 g) was chromatographed on silica gel. Ether, as eluting solvent, carried down **2c**: NMR (acetone) δ 1·15 (t, 7·1 Hz, 3H), 4·15 (q, 7·1 Hz, 2H), 5·31 (s, 2H), 7·52 (s, 5H), 7·81 (s, 1H); IR (liq) 1749, 1484, 1378, 767 cm^{-1}. (Found: C, 62·48; H, 5·72. Calcd for $C_{12}H_{13}N_3O_2$: C, 62·33; H, 5·67%).

4-*Phenyl*-1,2,3-*triazol*-1-*ylacetic* (**4a**) *and* 5-*phenyl*-1,2,3-*triazol*-1-*ylacetic* (**4b**) *acids*. The residue from the previous preparation was purified by crystallization to give more **2b** (12 g) and mother liquor. The latter was heated in 15% NaOH aq (40 ml) at 100°, then filtered through charcoal and acidified to give **4b** (yield 4·10 g, 21%), which was crystallized from water: m.p. 194–194·5° (lit.[35] 192–196°); NMR (acetone) δ 5·38 (s, 2H), 5·55 (broad 1H), 7·55 (s, 5H), 7·81 (s, 1H); IR (Nujol) 1717, 1128 cm^{-1}. The isomeric acid (**4a**) was obtained in quantitative yield from the ester (**2b**) by alkaline hydrolysis: m.p. 200–202°; NMR (acetone) δ 5·40 (s, 2H), 5·90 (broad 5H), 7·45 (m, 3H), 7·95 (m, 2H), 8·41 (s, 1H); IR (Nujol) 1731, 1098 cm^{-1}. (Found: C, 58·94; H, 4·39. Calcd. for $C_{10}H_9N_3O_2$: C, 59·11; H, 4·46%).

Directioselectivity in the reactions of 4-*phenyl*-1,2,3-*triazole in base with ethyl chloroacetate*. A soln of 4-phenyl-1,2,3-triazole (36 mg, 0·25 mmol), NaOMe (13·5 mg, 0·25 mmol) or 1,8-*bis*-dimethylaminonaphthalene (54 mg, 0·25 mmol), and ethyl chloroacetate (31 mg, 0·25 mmol) in EtOH or DMF (5 ml) was placed in an NMR tube. The soln was kept at 75° for 3 days, then cooled to *ca* 20° and its NMR spectrum taken. Two new methylene shifts were now present. The soln was hydrolyzed with dil HCl, evaporated, and the residue was dissolved in acetone (0·040 ml). By comparison of the NMR spectra with those of authentic samples of the phenyl-1,2,3-triazolylacetic acids,[14] the products could be identiified. Integration of the NMR peaks gave the figures of Table 2.

β-(4-*Phenyl*-1,2,3-*triazol*-1-yl)*propionic* (**4c**) *and* β-(4-*phenyl*-1,2,3-*triazol*-2-yl)*propionic* (**5b**) *acids*. A soln of 4-phenyl-1,2,3-triazole (0·50 g, 3·5 mmol) and NaOMe (0·16 g, 3·6 mmol) was stirred in DMF (10 ml) for 1 hr at ~ 25°. Ethyl β-chloropropionate (0·545 g, 4·0 mmol) was added, the mixture was heated at reflux for 45 hr, cooled, and treated with water and methylene chloride. On evaporation, the organic portion left a viscous liquid which was purified by chromatography on silica gel. The first ether eluate gave **3c** (0·150 g, 17%) and later ether eluates gave **2d** (0·230 g, 26%). The identity of the esters was established after they were saponified and the properties of the acid products compared with authentic samples. The acid **4c** had m.p. 178–180° (lit.[14] m.p. 177–179°). Compound **5b** had: m.p. 133–135° (lit.[14] m.p. 145–146°); NMR (acetone) δ 9·04 (s, 1H), 7·90 (m, 2H), 7·43 (m, 3H), 4·76 (t, 7·1 Hz, 2H), 3·09 (t, 7·1 Hz, 2H). None of the third isomer, ester (**2e**) or acid (**4d**), could be detected.

Ethyl β-(4,5-*dicarbomethoxy*-1,2,3-*triazol*-2-yl)-*acrylate* (**6a**). A soln of 4,5-dicarbomethoxy-1,2,3-triazole (0·548 g, 2·96 mmole), triethylamine (75 ml), and ethyl propiolate (0·294 g, 3·0 mmole) in acetone soln was heated at reflux

for *ca* 12 hr. Evaporation of the soln left a red-brown mobile liquid, which was chromatographed on silica gel. Carbon tetrachloride eluted *trans*-**6a** (0·35 g, 29%) and chloroform eluted *cis*-**6a** (0·24 g, 29%). The *trans* had: NMR ($CDCl_3$) δ 8·04 (d, 14·1 Hz, 1H), 6·74 (d, 14·1 Hz, 1H), 4·31 (q, 7·1 Hz, 2H), 4·00 (s, 6H), 1·34 (t, 7·1 Hz, 3H); IR (thin film) 1750–1715, 1656, 1290, 884, 850 cm^{-1}. (Found: C, 46·71; H, 4·76. Calcd for $C_{11}H_{13}N_3O_6$: C, 46·64; H, 4·63%).

The *cis* had: NMR ($CDCl_3$) δ 7·28 (d, 9·9 Hz, 1H), 6·04 (d, 9·9 Hz, 1H); 4·32 (q, 7·0 Hz, 2H), 3·99 (s, 6H), 1·31 (t, 7·0 Hz, 3H); IR (thin film) 1750–1730, 1665, 1405, 864, 838 cm^{-1}. (Found: C, 46·37; H, 4·83. Calcd for $C_{11}H_{13}N_3O_6$: C, 46·64; H, 4·63%).

Several experiments of the same general type as above were carried out to examine the ratio of *syn* to *anti* adduct under various conditions (Table 5). NMR analysis of the raw product in the region δ 5·5–8·5 indicated two kinds of ethylenic compounds as well as other materials (< 5%).

Dicarbomethoxy (4,5-*dicarboxymethyl*-1,2,3-*triazol*-2-yl) *ethylene* (**6b**). A soln of 4,5-dicarbomethoxy-1,2,3-triazole (0·535 g, 2·89 mmol), dimethyl acetylenedicarboxylate (0·415 g, 2·91 mmol) and triethylamine (0·05 ml) in acetone (5 ml) was kept at *ca* 25° for 3 days and evaporated to leave an oil. This was chromatographed on silica gel with CCl_4 and $CHCl_3$. The first fractions gave **6b** as a white solid (0·365 g, 39%): m.p. 113–114°; NMR δ (acetone) 8·30 (s, 2H); 3·96 (s, 6H); 3·89 (s, 3H); 3·87 (s, 1H): IR (film) 2952, 1745, 1654, 1458, 1233, 1103, 979 cm^{-1}. (Found: C, 44·11; H, 4·11. Calcd for $C_{12}H_{13}N_3O_8$: C, 44·04; H, 4·00%).

β-(4,5-*Dicarbomethoxy*-1,2,3-*triazol*-2-yl)*cinnamaldehyde* (**6c**). A soln of 4,5-dicarbomethoxy-1,2,3-triazole (1·17 g, 6·3 mmol), triethylamine (0·5 ml) and phenylpropiolaldehyde (0·825 g, 6·3 mmol) in THF (13 ml) was kept at −20° for 1 day, and then evaporated to dryness. The residue was chromatographed on silica gel with chloroform to give *anti* adduct in the first and the *syn* adduct in the later eluates. The *anti* adduct or *cis* (0·540 g, 27%) had: m.p. 107·5–108°; NMR ($CDCl_3$) δ 4·03 (s, 6H), 6·61 (d, 7·0 Hz, 1H), 7·60 (broad, 5H), 9·69 (d, 7·0 Hz, 1H); IR ($CHCl_3$) 1745, 1680, 1629 cm^{-1}. (Found: C, 57·04; H, 4·15. Calcd for $C_{15}H_{13}N_3O_5$: C, 57·16; H, 4·12%).

The *syn* adduct or *trans* (0·87 g, 44%) had: m.p. 151–152°; NMR ($CDCl_3$) δ 3·99 (s, 6H), 7·15 (d, 7·5 Hz, 1H), 7·56 (s, 5H), 9·52 (d, 7·5 Hz, 1H); IR ($CHCl_3$) 1745, 1677, 1624, 1330 cm^{-1}. (Found: C, 56·78; H, 3·92. Calcd for $C_{15}H_{13}N_3O_5$: C, 57·16; H, 4·12%).

anti *and* syn *Products of the addition of* H-1,2,3-*triazoles to phenylpropiolaldehyde*. A soln of 1,2,3-triazole (0·33 mmol), phenylpropiolaldehyde (43 mg, 0·33 mmol) and triethylamine (0·05 ml) in THF was left at 20–30° overnight and checked by NMR. The chemical shifts were observed and structural assignments made on the basis that $J_{CHCHO} = 6·9–7·0$ Hz for the *anti* and $J_{CHCHO} = 7·5–7·6$ Hz for *syn* adducts. The *anti* to *syn* product ratio was estimated from a peak integration of the aldehyde proton resonance. Data are given in Table 3.

Ethyl trans-(4-*phenyl*-1,2,3-*triazol*-2-yl) *acrylate* (**6d**). To a suspension of 4-phenyl-1,2,3-triazole (0·604 g, 4·16 mmol), NaOMe (0·225 g, 5·11 mmol) and EtOH (10 ml), which was stirred at ~ 25° for 1 hr, ethyl propiolate (0·407 g, 4·15 mmol) was added. The mixture was heated at reflux for 10 hr, cooled, and filtered. Removal of EtOH from the filtrate yielded a yellow liquid that was chromatographed on silica gel with CCl_4. This gave **6d** as a white solid (yield 0·52 g, 51%): m.p. 92–94°; NMR ($CHCl_3$) δ 8·22 (d, 13·8 Hz, 1H), 7·85 (m, 3H), 7·45 (m, 2H), 6·69 (d, 13·8 Hz, 1H), 4·27 (q, 7·0 Hz, 2H), 1·33 (t, 7·0 Hz, 3H); IR (CCl_4) 2980, 1742, 1723, 1653, 1483, 1463, 1288, 982, 960 (*trans* band), cm^{-1}. The analogous *cis* compound has been prepared.[14] (Found: C, 64·10; H, 5·35. Calcd for $C_{13}H_{13}N_3O_2$: C, 64·18; H, 5·39%).

Ethyl β-(4-*phenyl*-5-*carbethoxy*-1,2,3-*triazol*-2-yl)-*cinnamate* (**6e**). A mixture of ethyl phenyl propiolate (3·05 g, 17·5 mmol) and sodium azide (1·16 g, 17·6 mmol) in DMF (50 ml) was heated at 60° with stirring for 5 hr and put aside at ~ 25° for 12 hr. After water (50 ml) was added, the mixture was acidified with HCl and extracted twice with ether (50 ml). The extract was dried with Na_2SO_4 and evaporated to leave a white solid (**6e**) which was recrystallized from ether (0·440 g, 12·8%): m.p. 107°; NMR ($CDCl_3$) δ 1·12 (t, 7·2 Hz, 3H), 1·15 (t, 7·2 Hz, 3H), 4·10 (q, 7·2 Hz, 2H), 5·62 (q, 7·2 Hz, 2H), 7·08 (s, 1H), 7·45 (s, 5H), 7·7–7·3 (m, 3H), 8·0–7·7 (m, 2H); IR ($CHCl_3$) 1724 cm^{-1}. (Found: C, 67·40; H, 5·51. Calcd for $C_{22}H_{21}N_3O_4$: C, 67·50; H, 5·41%).

The water layer from the above extraction was evaporated and the residue extracted with dichloromethane. This was worked up to give 4-phenyl-5-carbethoxy-1,2,3-triazole (2·58 g, 68%), m.p. 91–92° (lit.[14] m.p. 91–92°).

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