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X=Y-ZH COMPOUNDS AS POTENTIAL 1,3-DIPOLES. PART 24.[1,2] PREPARATION AND THERMAL FRAGMENTATION OF IMIDAZOLIDINES. INFLUENCE OF METAL SALTS ON PYRROLIDINE VERSUS IMIDAZOLIDINE FORMATION

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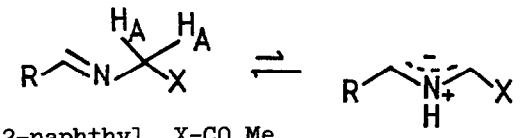
Abstract. Imines of diethyl aminomalonate slowly dimerise to imidazolidines in ethanol or methylene chloride at 40°C, but cycloaddition to other imines does not occur. Imines of glycine, alanine and phenylglycine methyl esters undergo rapid regio- and stereo-specific cycloaddition to methyl acrylate (MeCN, 25°C) in the presence of Ag(I) or Mn(II) salts, and triethylamine, whilst Zn(II) or Co(II) salts dimerise the imines to imidazolidines. In the latter case cycloaddition to other imines also occurs. Use of Mg(II) salts can lead to either pyrrolidines or imidazolidines depending on the salt used. A correlation with metal cation hydration enthalpies is noted. Heating imidazolidines in the presence of dipolarophiles effects a tandem cyclo-reversion-cycloaddition process leading to new cycloadducts.

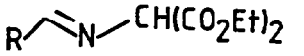
We have shown that the thermal generation of azomethine ylides (2) from imines (1) is a function of the basicity of the imino nitrogen atom and the pK_a of the azaallylic protons H_A[3]. Moreover, a wide variety of X groups in (1), including the ester group, lower the pK_a of the H_A protons sufficiently to promote the 1,2-prototropy[4]. Recently pK_a values for several arylidene imines of α-amino acid esters have been reported.[5] In certain cases, e.g. (1, X=2-pyridyl) the imines slowly dimerise to imidazolidines on standing at room temperature.[4] The presence of two ester groups in the imines (3) promotes an analogous dimerisation[2] and we have recently found that imines with a single ester activating group can also be induced to dimerise or cycloadd to other imines in the presence of certain metal salts giving imidazolidines. Full details of these studies are now reported.

Attempts to prepare imines of diethyl aminomalonate by reacting its hydrochloride with arylaldehydes in ethanol containing sodium ethoxide (1mol) invariably led to mixtures of the desired imine (3) and a second dimeric product. Extended reaction times and carrying out the reaction at

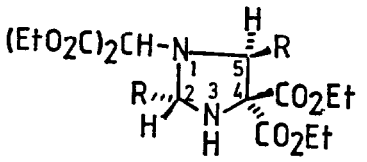


(1) a. R=2-naphthyl, X=CO_2Me
b. R=2-naphthyl, X=2-pyridyl
c. R=Ph, X=CO_2Me

(2)



(3) a. R=5-(2-phenylthiazolyl)
b. R=p-$MeOC_6H_4$
c. R=2-furyl
d. R=2-thienyl



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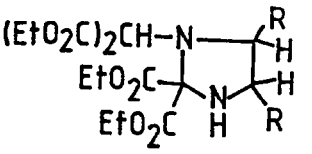

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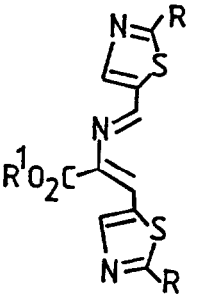


(6) a. R=Ph, R^1=Me
b. R=R^1=Me

Table 1. Formation of imidazolidines (4) by reaction of aryl and heteroaryl aldehydes with diethyl aminomalonate

	R	Reaction[a] Conditions	Time(h)	Yield(%)[b]
a.	5-(2-phenylthiazolyl)	A	96	60
b.	Ph	A	48	53
c.	p-$O_2NC_6H_4$	A	120	47
d.	2-pyridyl	B	18	45
e.	p-$MeOC_6H_4$	B	96	-[c]
f.	2-furyl	B	96	-[d]
g.	2-thienyl	B	96	-[e]

a. A: reaction carried out in ethanol at 40°C
B: reaction carried out in boiling methylene chloride
b. Isolated yield
c. Product comprised a 2:1 mixture of imine (3b) and (4e)
d. Product comprised a 1:2.5 mixture of imine (3c) and (4f)
e. Product comprised a 5:1 mixture of imine (3d) and (4g).

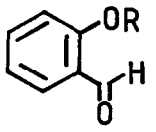
40°C resulted in formation of mainly the dimeric product in some cases and this dimeric product proved to be the imidazolidine (4)(Table 1). Thus 2-phenylthiazole-5-carboxaldehyde reacts (EtOH, 40°C) with diethyl aminomalonate over four days to give dimer [4, R=5-(2-phenylthiazolyl)](60%) (Table 1). Similar results were obtained using benzaldehyde and p-nitrobenzaldehyde (Table 1). Diethyl aminomalonate free base reacts with arylaldehydes in boiling methylene chloride also to give mixtures of the corresponding imines and dimers except in the case of 2-pyridylaldehyde which furnished only the dimer (4, R=2-pyridyl). In cases where dimer formation is especially slow use of methylene chloride as solvent results in a cleaner reaction.

The structures of the imidazolidines (4) are assigned on the basis of their ^{1}H n.m.r. spectra. In particular the alternative imidazolidine structure (5) is ruled out by the appearance of two singlets for the 2-H and 5-H protons between δ 5-6. The methylene protons and methyl groups of the ethoxycarbonyl moieties in (4) are magnetically non-equivalent and give rise to separate multiplets. The imidazolidines (4) are produced as single regio- and stereo-isomers and are assigned the trans-stereochemistry by analogy with our results on related imidazolidines[4], and on the basis of the absence of a ^{1}H NOEDSY enhancement between the 2-H and 5-H protons.

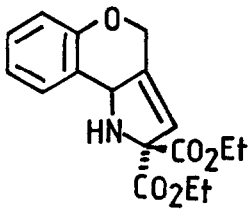
Attempts to effect a crossed-cycloaddition by reaction of 2-phenylthiazole-5-carboxaldehyde, benzylidene aniline and diethyl aminomalonate hydrochloride in methanol containing sodium methoxide (1mol) led instead to the formation of (6a)(27%), i.e. a product in which both monodecarboxylation and transesterification had occurred. The methyl esters (6a) and (6b) could also be prepared from methyl glycinate and the appropriate thiazole aldehyde.

Two examples of intramolecular cycloadditions involving 1,2-prototropy were studied (toluene, 110°C, 48h) utilising diethyl aminomalonate and the aldehydes (7a) and (7b), and resulting in the formation of (8)(90%) and (9)(50%) respectively. The cis-ring junction stereochemistry in (9) is assigned by analogy with our previously reported studies.[5]

Formation of imidazolidines (4) from imines (3) could involve an anionic ($4\pi + 2\pi$) cycloaddition of the type originally discovered and exploited by Kaufmann[7] which involve azaallylic anions with lithium counterions. We subsequently demonstrated the ability of tertiary amines and pyridine to catalyse the cycloaddition of imines of α-amino acid esters to electro negative olefins[8,9] whilst Cawhill and Clark have reported an anionic cyclo dimerisation of (10) with subsequent loss of hydrogen cyanide to give imidazoles[10]. It seems probable that both the azaallyl anion (11) and the azomethine ylide (12) are present in the reactions carried out in ethanol with, perhaps, both participating in the cycloaddition.



(7) a. $R=CH_2C{\equiv}CH$
b. $R=CH_2CH{=}CH_2$



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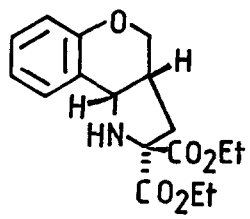

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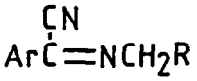

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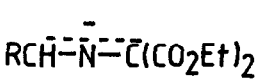

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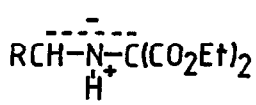
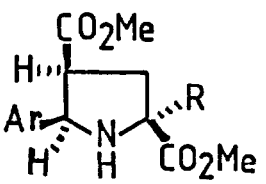


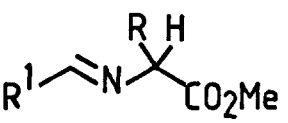
(12)

Following earlier work on the effect of Bronsted and Lewis acid catalysts on the generation of azomethine ylides from imines[8] we subsequently showed that a combination of metal salt (silver, lithium or zinc) and triethylamine in dipolar aprotic solvents (MeCN, DMSO, DMF), or N-methylacetamide, effects rapid regio- and stereo-specific or highly stereoselective inter- and intra-molecular cycloaddition of arylidene imines of α-amino acid esters to electronegative olefins at room temperature.[4,11] The nature of the species involved in these cycloadditions is unclear but we suggested that equilibria involving metallo-1,3-dipoles[12] and N-protonated azomethine ylides were involved. Further studies have revealed interesting reactivity differences (Michael addition versus cycloaddition) between lithium and silver salts.[13]

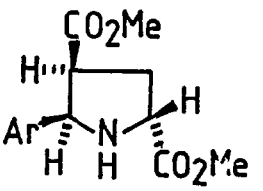
As part of a wider survey we have studied the effect of various metal salt (1.5mol)-triethylamine (1mol) combinations on the cycloaddition of (1a), (14a) and (14b) with methyl acrylate (Table 2) to give pyrrolidines (13a-c).



(13) a. Ar=2-naphthyl, R=H
b. Ar=2-naphthyl, R=Me
c. Ar=R=Ph



(14) a. R=Me, R^1=2-naphthyl
b. $R=R^1$=Ph



(15) Ar=2-naphthyl

Silver nitrate and silver carbonate are effective catalysts for the reaction of (1a) and methyl acrylate to give (13a), but the reaction in the presence of silver nitrate is both faster and gives a better yield

Table 2. Cycloaddition of imines and methyl acrylate to give pyrrolidines (13a-c).[a]

Imine	Metal Salt	Solvent	Reaction time(h)	Product	Yield(%)[b]
1a	$AgNO_3$	MeCN	0.5	13a	87
1a	Ag_2CO_3	MeCN	3.5	13a	67
1a	Ag_2 tartrate	MeCN	5.0	13a	61
1a	Ag_2 (o-benzoyl) tartrate	MeCN	2.0	13a	51
1a	$MnBr_2$	MeCN	1.0	13a	67
1a	$MgBr_2.Et_2O$	MeCN	2.0	13a	50[c]
14a	$MnBr_2$	MeCN	0.5	13b	70
14b	$MgBr_2.Et_2O$	MeCN	0.5	13c	53
14b	Et_2NMgBr	Et_2O	6.0	13c	60

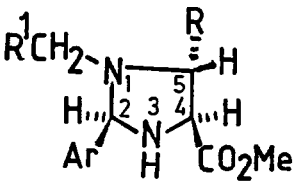
a. All reactions carried out at room temperature in dry solvents using imine (1mol), methyl acrylate (2.5mol) metal salt (1.5mol), and triethylamine (1mol); b. Isolated yield.

c. Product comprises a 4.1:1 mixture of (13a) and (15).

(87% versus 67%)(Table 2). The disilver salts of L-tartaric acid and di(O-benzoyl)-L-tartaric acid also effect the cycloaddition but give products devoid of optical activity (Table 2). Manganous bromide also gives (13a) in good yield whilst magnesium bromide is less efficient (Table 2). Imines (14a) and (14b) undergo analogous cycloadditions to methyl acrylate in the presence of $MnBr_2$ or Mg(II) salts giving (13b) and (13c) respectively in 53-70% yield (Table 2).

In contrast to the formation of pyrrolidines using the metal salts listed in Table 2, when the reaction (MeCN, 25°C) of (1a) and methyl acrylate was carried out in the presence of cobaltous chloride, magnesium perchlorate, or zinc bromide, the product was a mixture of imidazolidines (16a) and (17a). Crossed cycloadditions can also be effected and the results of a brief survey of the reaction are summarised in Table 3.

Formation of imidazolidines (16) & (17) proceeded less efficiently or not at all when triethylamine (1mol) was present. The generally low to moderate yields of imidazolidines (16) and (17) are in part accounted for by accompanying hydrolysis of the imines. In previous publications[8,11] we have drawn attention to the tendency of certain metal ions to generate Bronsted acids by coordination of water in ostensibly dry solvents (19) (20). Magnesium and zinc salts are especially prone to such behaviour.[14]



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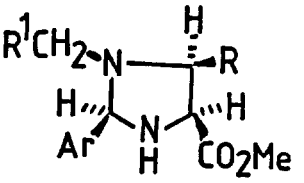
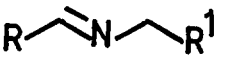


(17)

a. Ar=R=2-naphthyl, $R^1 = CO_2Me$
b. Ar=R=2-naphthyl, $R^1 = H$
c. Ar=R=2-naphthyl, $R^1 = Ph$



(18)

a. R=2-naphthyl, R^1=H
b. R=2-naphthyl, R^1=Ph
c. R=R^1=Ph

Table 3. Imidazolidines from the cycloaddition of imines (1a-c) with imines (18a-c) as dipolarophiles in the presence of metal salts.[a]

Imine	Dipolarophile	Metal Salt	Reaction time(h)	Product (Ratio)	Yield (%)
1a	1a	$MgClO_4$	6.5	16a(1.2),17a(1)	50
1a	1a	$CoCl_2$	3.5	16a(1.2),17a(1)	57
1a	18a	$MgClO_4$	7.0	16b(1.7),17b(1)	34
1a	18a	$ZnBr_2$	20.0	16b(3.5),17b(1)	70
1a	18b	$ZnBr_2$	16.0	16c(4.5),17c(1)	53
1a	18c	$ZnBr_2$	16.0	16d-[c]	21
1c	18b	$ZnBr_2$	18.0	16e-[c]	30

a. All reactions carried out in dry acetonitrile at room temperature using imine (1mol), dipolarophile (4mol) and anhydrous metal salt (1.5mol).
b. Isolated yield; c. Trans-isomer only.

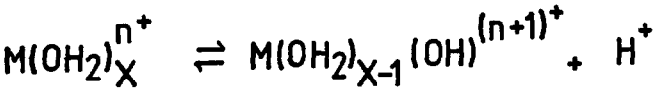
Thus the involvement of Bronsted acid catalysis in the formation of (16) and (17) seemed a strong possibility. Supporting evidence was provided by the observation that when imine (1a) in acetonitrile at 25°C was treated with 1mol. of perchloric acid (added as a 70% aqueous solution), hydrogen bromide, trifluoroacetic acid or acetic acid, the same mixture of dimers (16a) and (17a) was obtained in varying yield together with hydrolysis products of the imine. N.m.r. tube reactions using fresh ampoules of CD_3CO_2D or CF_3CO_2D, and CD_3CN as solvent give rise to noticeably slower dimerisation of (1a), implicating an accelerating effect of small amounts of water even in these Bronsted acid catalysed cases. These and the previous results suggest that the dipolarophile involved in imidazolidine

formation is the protonated imine (21). By the same token, it is likely that in the majority of these reactions the reactive 1,3-dipole is (23) rather than a metallo-1,3-dipole.[11-13] Attempts to use the Mannich salt (22) as a dipolarophile were unsuccessful, presumably due to the instability of the resulting imidazolidinium salt. Whilst the factors influencing the ratio of (16) and (17) are not identifiable from our brief survey, it is noteworthy that the use of zinc bromide gives rise to a much higher proportion of the trans-isomer (16). The stereochemistry of (16) and (17) is based on ^{1}H NOEDSY experiments. Thus (17b) shows positive ^{1}H NOEDSY enhancements between the 2-H and 5-H protons, and between the 4-H and 5-H protons. Imidazolidine (16b) shows a positive ^{1}H NOEDSY enhancement between 2-H and 4-H but not between 2-H and 5-H (see experimental section). The imidazolidines (16) and (17) are thus derived from azomethine ylide (2) (or its metallo-1,3-dipole equivalent) via exo- (with respect to R) and endo-transition states respectively.

The divergent behaviour of the metal salts leading to pyrrolidines or imidazolidines is clearly a function, at least in part, of the counterions since use of magnesium perchlorate leads to imidazolidines, whilst use of $MgBr_2.OEt_2$ or Et_2NMgBr leads to pyrrolidines. There is no correlation with metal cation radii but there is a reasonable correlation with the single ion hydration enthalpies for the metal cations. Those with low ion hydration enthalpies (Table 4) favour pyrrolidine formation, whilst those with the highest enthalpies favour imidazolidine formation. This supports our contention that Bronsted acid formation (19) $\rightleftharpoons$ (20) is important in imidazolidine formation. The values in Table 4 will, of course, be modified in acetonitrile by both the solvent and the counterions as will the pK_a of the coordinated water molecules. Both pyrrolidine (13) and imidazolidine (16), (17), formation involve stereospecific dipole formation as observed in our previous studies.[11]

The imidazolidines (4) are thermally labile and on heating in boiling toluene in the presence of N-phenylmaleimide, maleic anhydride, or diethyl azodicarboxylate give (25a), (25b) and (26) respectively. The cyclo-reversion, which is slow at 110°C, is analogous to that observed for pyrrolidines[16], pyrazolidines[17], and certain other 5-membered heterocycles.[18] The yields (Table 4) of pyrrolidines from (4) frequently exceed 50% showing that the imine generated in the cycloreversion also functions as a source of a 1,3-dipole (Scheme) via 1,2-prototropy.[3,4]

Although no accurate rate studies were performed the reactions were monitored by ^{1}H n.m.r. and the results in Table 4 clearly indicate the retarding effect, on the rate of cycloreversion of (4), exerted by the p-$O_2NC_6H_4$ substituent.[19] Dipole formation is rate determining in



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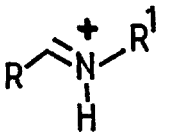

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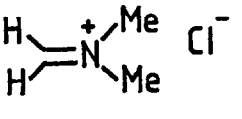

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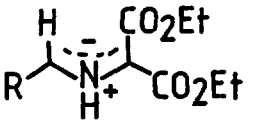
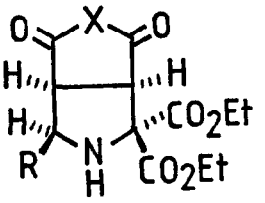
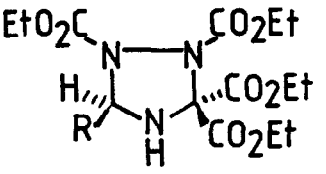


(23)

(24) a. X=NPh
b. X=O



(25) a. X=NPh
b. X=O



(26) a. R=Ph
b. R=p-$O_2NC_6H_4$

Table 4. Single ion hydration enthalpies for metal cations.[15]

Cation	Hydration enthalpy (kcal mol^{-1})
Ag(I)	-113.6
Li(I)	-123.0
Mn(II)	-441.0
Mg(II)	-459.4
Zn(II)	-488.6
Co(II)	-491.0

cycloadditions employing maleimides as dipolarophiles in which azomethine ylides are generated by 1,2-prototropy[19] or cycloreversion.[20] This retarding effect is thus related to dipole formation and can be accommodated by a concerted but non-synchronous cycloreversion in which 2,3-bond cleavage in (4) is in advance of 4,5-bond cleavage. The stereochemistry of (25a) and (25b) is assigned by analogy with our previous results on the cycloaddition of azomethine ylides to cyclic dipolarophiles[21] and to related studies involving azomethine ylides generated by thermal cycloreversion of the imidazolidines derived from spontaneous dimerisation of imines of homo-

Table 5. Pyrrolidines (25) and triazolidines (26) from the thermal cycloreversion of imidazolidines (4) in the presence of cyclic dipolarophiles (24) or diethyl azodicarboxylate.[a]

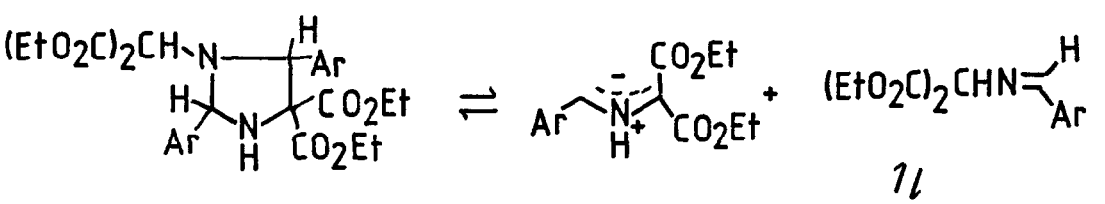
Imidazolidine	Dipolarophile	Reaction time(d)	Product	Yield(%)[b]
4a	24a	1	25a, R=5-(2-phenyl-thiazolyl)	51
4b	24a	1	25a, R=Ph	52
4c	24a	5	25a, R=p-$O_2NC_6H_4$	62
4d	24a	1	25a, R=2-pyridyl	65
4e	24a	1	25a, R=p-$MeOC_6H_4$	73
4f	24a	1	25a, R=2-furyl	56
4g	24a	1	25a, R=2-thienyl	43
4a	24b	1	25b, R=5-(2-phenyl-thiazolyl)	75
4b	24b	1	25b, R=Ph	71
4c	24b	3	25b, R=p-$O_2NC_6H_4$	47
4b	DEAD[c]	3	26a	52
4c	DEAD[c]	8	26b	8

a. Reactions carried out in boiling toluene using imidazolidine (1mol) and dipolarophile (2mol).

b. Isolated yield.

c. DEAD = diethyl azodicarboxylate.

cysteine and 2-aminomethylpyridine.[4] Recently others have reported on the cycloadditions of azomethine ylides derived from formaldehyde and diethyl aminomalonate.[22]



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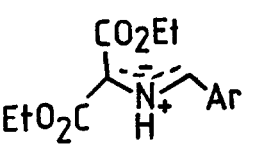

Experimental

General experimental details were as previously noted.[11] Petroleum ether refers to the fraction with b.p. 60-80°C. Anhydrous metal salts were used as purchased. Anhydrous $CoCl_2$ was prepared from the red hydrated salt by boiling in 2,2-dimethoxypropane for 4h. followed by removal of the solvent and drying in vacuo (0.1mmHg) at 110°C for 24h.

Disilver salt of L-tartaric acid. The method is an adaptation of that used for the monosilver salt.[23] L-Tartaric acid (10g, 6.6mmol) was dissolved in distilled water (300ml) and 35% w/w aqueous ammonium hydroxide (7.29ml, 13.2mmol) added. A solution of silver nitrate (22.44g, 13.2mmol) in distilled water (100ml) was then added dropwise over 30 min. The disilver salt precipitated and was removed by filtration, washed with distilled water (2 x 20ml) and dried, with exclusion of light, to afford the product (12.5g, 52%) as colourless prisms, m.p. 178-182°C(d) (Found: Ag, 58.6. $C_4H_4O_6Ag_2.0.25H_2O$ requires Ag, 58.60%). The compound was too insoluble for its nmr spectrum to be determined.

Disilver salt of O-dibenzoyl-L-tartaric acid. Prepared in an analogous manner to that described above except that it was necessary to heat the solution to dissolve the ammonium salt and the addition of the aqueous silver nitrate solution was carried out at 40°C. The product (47%) was obtained as colourless needles, m.p. 182-185°C(d) (Found: Ag, 37.30. $C_{18}H_{12}O_8Ag$ requires Ag, 37.70%). The compound was too insoluble for its nmr spectrum to be determined.

Imidazolidines (4)

General Procedure. A). A solution of the aldehyde (42.3mmol) in dry ethanol (120ml) was added to a mixture of diethyl aminomalonate (42.3mmol) and sodium ethoxide [from sodium (1g)] in dry ethanol (200ml). The mixture was stirred at 40°C under nitrogen for the time shown in Table 1. The reaction mixture was then evaporated under reduced pressure, the residue dissolved in methylene chloride, washed with water and dried (Na_2SO_4). Removal of the methylene chloride followed by crystallisation from ether-petroleum ether afforded the product. Yields are given in Table 1.

B). The aldehyde (5mmol), and diethyl aminomalonate (5.5mmol) were dissolved in methylene chloride (50ml) and anhydrous sodium sulphate (1g) added. The mixture was stirred and boiled under reflux for the time shown in Table 1. The reaction mixture was then filtered and the filtrate evaporated to afford the solid dimer, in the case of (4d), or a mixture of imine (3) and dimer (4) as a thick yellow oil. The ratio of (3) to (4) was obtained from the p.m.r. spectrum of the crude material. The mixtures were used for cyclo-

addition reactions without further purification.

1-Di(ethoxycarbonyl)methyl-2,5-di[5'-(2'-phenylthiazolyl)]-4,4-diethoxy carbonylimidazolidine (4a). Obtained as a colourless rods, m.p. 113-115°C (Found: C, 59.10, H, 5.55; N, 8.05. $C_{34}H_{36}N_4O_8S_2$ requires C, 58.95; H, 5.20; N, 8.10%); δ 7.45 (m, 10H, ArH), 7.99 & 7.75 (2xs, 2x1H, thiazolyl-H) 5.88 and 5.54 (2xs, 2x1H, 2-H and 5-H), 4.27 (s, 1H, $NCHCO_2R$), 4.55-3.75 (m, 8H, $\underline{CH_2}Me$) and 1.37, 1.21, 1.06 and 1.00 (4xt, 4x3H, $CH_2\underline{Me}$); ν_{max} 3250, 1745, 1235 and 1025 cm^{-1}.

1-Di(ethoxycarbonyl)methyl-2,5-diphenyl-4,4-diethoxycarbonylimidazolidine (4b). Obtained as colourless needles, m.p. 118-121°C (Found: C, 64.15; H, 6.55; N, 5.20. $C_{28}H_{34}N_2O_8$ requires C, 63.90; H, 6.45; N, 5.30%); δ 7.51 (m, 10H, ArH), 5.64 and 5.29 (2xs, 2x1H, 2-H and 5-H), 4.07 (s, 1H, $NCHCO_2R$), 4.35 and 3.54 (2xm, 2x4H, $\underline{CH_2}Me$) and 1.28, 1.12, 1.05 and 0.78 (4xt, 4x3H, $CH_2\underline{Me}$); m/z(%) 526 (M^+,1), 367(17), 264(100), 190(35), 117(43) and 116(25); ν_{max} 3320, 1745, 1730, 1370 and 1030 cm^{-1}.

1-Di(ethoxycarbonyl)methyl-2,5-(4'-nitrophenyl)-4,4-diethoxycarbonyl imidazolidine (4c). Obtained as colourless needles, m.p. 130-133°C (Found: C, 54.40; H, 5.10; N, 9.05. $C_{28}H_{32}N_4O_{12}$ requires C, 54.55; H, 5.20; N, 9.10%); δ 8.3, 8.21, 7.89 and 7.74 (4xd, 4x2H, ArH), 5.74 and 5.45 (2xs, 2x1H, 2-H and 5-H), 4.00 (s, 1H, $NCHCO_2R$), 4.39 and 3.66 (2xm, 2x4H, $\underline{CH_2}Me$) and 1.25, 1.16, 1.06 and 0.84 (4xt, 4x3H, $CH_2\underline{Me}$); m/z(%) 543(1), 235(100), 207(37), 161(28), 160(29) and 89(35); ν_{max} 3320, 1745, 1520, 1350 and 1150 cm^{-1}.

1-Di(ethoxycarbonyl)methyl-2,5-di(2'-pyridyl)-4,4-diethoxycarbonyl imidazolidine (4d). Pale yellow prisms, m.p. 80-82°C (Found: C, 56.50; H, 6.40; N, 10.55. $C_{26}H_{32}N_4O_8.1.5H_2O$ requires C, 56.20; H, 6.30; N, 10.10%); δ 8.7-7.13 (m, 8H, ArH + PyH), 5.6 (s, 1H, 5-H), 5.3 (br s, 1H, 2-H), 4.4-3.7 (m, 8H, 4 x $\underline{CH_2}Me$), 4.18 (s, 1H, $CHCO_2R$), and 1.3-1.0 (4xt, 4x3H, $4xCH_2\underline{Me}$); m/z(%) 528 (M^+,1), 455(28), 450(2), 365(4), 265(2), 191(100), 118(39) and 92(30).

1-Di(ethoxycarbonyl)methyl-2,5-di(4'-methoxyphenyl)-4,4-diethoxycarbonyl imidazolidine (4e). Obtained as a thick colourless oil whose p.m.r. spectrum showed it to comprise a 2:1 mixture of imine (3b) and imidazolidine (4e). Attempted purification led to decomposition and this mixture was therefore used directly for the preparation (25a, R=p-$MeOC_6H_4$) as described below.

(3b) δ 8.25 (s, 1H, CH=N), 7.8 and 6.9 (2xd, 2x2H, ArH), 4.9 (s, 1H, $CHCO_2R$), 4.20 (m, 4H, $2x\underline{CH_2}Me$), 3.85 (s, 3H, OMe) and 1.25 (m, 6H, $2xCH_2\underline{Me}$).

(4e) δ 7.6, 7.4, 6.9 and 6.8 (4xd, 4x2H, ArH), 5.6 (s, 1H, 2-H), 5.2 (s, 1H, 5-H), 4.0 (s, 1H, $CHCO_2R$), 4.2-3.6 (m, 8H, $4x\underline{CH_2}Me$), 3.8 and 3.75 (2xs, 2x3H, OMe), and 1.3-0.8 (4xt, 4x3H, $CH_2\underline{Me}$).

1-Di(ethoxycarbonyl)methyl-2,5-di(2'-furyl)-4,4-diethoxycarbonyl imidazolidine (4f). Obtained as a thick pale yellow oil whose p.m.r. spectrum showed it to comprise a 1:2.5 mixture of (3c) and imidazolidine (4f) Attempted purification led to decomposition and this mixture was therefore used directly in cycloreversion-cycloaddition reactions as described below.
(3c) δ 8.2 (s, 1H, CH=N), 7.4-6.0 (m, 6H, furyl-H), 4.8 (s, 1H, NCH), 4.2 (m, 4H, 2x$\underline{CH_2}$Me) and 1.2 (m, 6H, 2x$CH_2\underline{Me}$).
(4f) δ 7.4-6.0 (m, 6H, furyl-H), 5.4 (s, 1H, 5-H), 5.18 (br s, 1H, 2-H), 4.15 (s, 1H, $CHCO_2R$), 4.4-3.7 (m, 8H, 4x$\underline{CH_2}$Me) and 1.3-1.0 (4xt, 4x3H, $CH_2\underline{Me}$).
1-Di(ethoxycarbonyl)methyl-2,5-di(2'-thienyl)-4,4-diethoxycarbonyl imidazolidine (4g). Obtained as a thick yellow oil whose p.m.r. spectrum showed it to comprise a 5:1 mixture of (3d) and (4g).
(3g) δ 8.5 (s, 1H, CH=N), 7.3 (m, 3H, thienyl-H), 4.85 (s, 1H, $CHCO_2R$), 4.2 (m, 4H, 2x$\underline{CH_2}$Me) and 1.2 (m, 6H, 2x$CH_2\underline{Me}$).
(4g) δ 7.4-6.9 (m, 6H, thienyl-H), 5.9 (s, 1H, 5-H), 5.3 (s, 1H, 2-H), 4.2-3.6 (m, 9H, 4x$\underline{CH_2}$Me and $CHCO_2R$) and 1.2-0.9 (4xt, 12H, $CH_2\underline{Me}$).

2-Azabutadienes

1,4-Di[5'-(2'-phenylthiazolyl)]-3-methoxycarbonyl-2-azabutadiene (6a).
(a). 2-Phenylthiazole-5-carboxaldehyde (1.89g, 1mmol) in dry methanol (25ml) was added in one portion to a stirred solution of diethyl aminomalonate in dry methanol [prepared by neutralisation of the corresponding hydrochloride salt (2.2g, 1.05mmol) with sodium methoxide (from sodium 0.25g, 1.1mmol)] at 40°C. The mixture was stirred for a further 16h and then evaporated to dryness under reduced pressure. The residue was dissolved in methylene chloride, washed with water, dried (Na_2SO_4) and evaporated to dryness. Crystallisation of the solid residue from methylene chloride-ethanol afforded the product (520mg, 24%), as yellow-orange needles, m.p.206-208°C (d) (Found: C, 62.65; H, 3.85; N, 9.55. $C_{23}H_{17}N_3O_2S$ requires C, 62.85; H, 3.95; N, 9.75%); δ 9.28 and 8.19 (2xs, 2x1H, CH=N and $CH=CCO_2R$), 8.04 and 7.46 (2xm, 10H, ArH), 8.0 and 7.63 (2xs, 2x1H, thiazolyl-H) and 3.88 (s, 3H, OMe); m/z(%) 431 (M^+,100), 204(46), 166(41) and 121(42); ν_{max} 1718, 1710, 1630, 1600, 1415, 1230 and 1100 cm^{-1}.
(b). Glycine methyl ester hydrochloride (1mmol), sodium methoxide (1.1mmol) and 2-phenylthiazole-5-carboxaldehyde (1mmol) in methanol (50ml) at 40°C for 16h also gave (6a)(29%).
1,4-Di[5'-(2'-methylthiazolyl)]-3-methoxycarbonyl-2-azabutadiene (6b).
A similar procedure to (b)(above) using 2-methylthiazole-5-carboxaldehyde (0.8mmol), glycine methyl ester hydrochloride (0.7mmol) and sodium carbonate (0.4mmol) in water (20ml) at 40°C for 4dy afforded the product (360mg,

30%), brown needles from ethanol, m.p. 182-184°C (Found: C, 50.70; H, 4.30; N, 13.60. $C_{13}H_{13}N_3O_2S_2$ requires C, 50.80; H, 4.25; N, 13.70%); δ 9.10 (s, 1H, CH=N), 7.93 (s, 1H, $CH=CCO_2R$), 7.88 and 7.50 (2xs, 2x1H, thiazolyl-H), 3.80 (s, 3H, OMe), and 2.79 and 2.72 (2xs, 2x3H, thiazolyl-Me); m/z(%) 307 (M^+,100), 206(14), 166(19) and 142(29); ν_{max} 1700, 1600, 1180 and 1100 cm^{-1}.

Intramolecular Cycloadditions

2,2-Di(ethoxycarbonyl)-4H-2,9b-dihydropyrro[2,3-d]benzo[b]pyran (8). A mixture of O-propargyl salicylaldehyde (1.2g, 0.75mmol), and diethyl aminomalonate [generated by neutralisation of the corresponding hydrochloride salt (1.74g, 0.82mmol) with sodium bicarbonate (690mg, 0.82mmol) and extraction of the free base with ether] in dry toluene (80ml) was boiled under reflux for 2dy. The solvent was then evaporated under reduced pressure and the residual oil crystallised from ether-petroleum ether to afford the product (2.14g, 90%) as colourless rhombs, m.p. 77-79°C (Found: C, 64.20; H, 6.15; H, 4.60. $C_{17}H_{19}NO_5$ requires C, 64.35; H, 6.00; N, 4.40%); δ 7.04 (m, 4H, ArH), 5.86 (m, 1H, =CH), 5.17 (br s, 1H, CHN), 4.88 (m,2H,CH_2O), 4.26 and 4.18 (2xq, 2x2H, $\underline{CH_2}Me$), 3.72 (br,1H, exchangeable with D_2O, NH) and 1.24 and 1.22 (2xt, 2x3H, $CH_2\underline{Me}$); m/z(%) 317 (M^+,2), 245(26), 244(100), 243(12), 172(16), 171(70) and 170(20); ν_{max} 3340, 1725, 1600, 1575, 1480 and 1365 cm^{-1}.

2,2-Di(ethoxycarbonyl)-4H-2,3,3a,9b-tetrahydropyrro[2,3-d]benzo[b]pyran (9). An analogous reaction using O-allyl salicylaldehyde in place of O-propargyl salicylaldehyde afforded the product (50%) as colourless rods from ether-petroleum ether, m.p. 64-67°C (Found: C, 63.80; H, 6.35; N, 4.50. $C_{17}H_{21}NO_5$ requires C, 63.95; H, 6.60; N, 4.40%); δ 7.07 (m, 4H, ArH), 4.29 (m, 3H, $\underline{CH_2}Me$ + CHN), 4.15 (m, 2H, $\underline{CH_2}Me$), 4.08 (dd, 1H, CHOR), 3.82 (t, 1H, CHOR), 2.58 and 2.31 (2xdd, 2x1H, $\underline{CH_2}CH$), 2.53 (m, 1H, $CH_2\underline{CH}CH_2OR$) and 1.28 and 1.19 (2xt, 2x3H, $CH_2\underline{Me}$); m/z(%) 319 (M^+,4), 247(34), 246(100), 172(16), 131(10), 86(8) and 84(13); ν_{max} 3340, 1740, 1610, 1590, 1490 and 1050 cm^{-1}.

Pyrrolidines from Metal Salt-Triethylamine Catalysed Cycloaddition of Imines and Methyl Acrylate

General Procedure. A mixture of imine (1.74mmol), methyl acrylate (4.16mmol) metal salt (2.61mmol) and triethylamine (1.74mmol) in dry acetonitrile (25ml) was stirred at room temperature for the time noted in Table 2. The mixture was then filtered, the solvent removed under reduced pressure, the residue

dissolved in methylene chloride (50ml) and washed with water (3 x 50ml). After drying (anhy. $MgSO_4$) the methylene chloride solution was evaporated to afford the product. Yields are collected in Table 2.

Dimethyl c-5(2-naphthyl)-r-2,c-4-pyrrolidine dicarboxylate (13a). Obtained as a thick colourless oil from reactions employing the metal salts listed in Table 2. The product had identical spectroscopic data to that described previously.[11]

Dimethyl 2-methyl-c-5(2-naphthyl)-r-2,c-4-pyrrolidine dicarboxylate (13b). Colourless prisms from 40-60°C petroleum ether-ether, m.p. 96-97°C (Found: C, 69.95; H, 6.60; N,4.00. $C_{19}H_{21}NO_4$ requires C, 69.70; H, 6.45; N, 4.30%); δ 7.78 (m, 4H, ArH), 7.44 (m, 3H, ArH), 4.78 (d, 1H, J 7.3Hz, 5-H), 3.83 (s, 3H, OMe), 3.41 (m, 1H, 4-H), 3.12 (br s, 1H, NH), 3.09 (s, 3H, OMe), 2.78 (dd, 1H, J 4.8 and 13.6Hz, 3-H), 2.07 (dd, 1H, J 7.5 and 13.6Hz, 3-H) and 1.53 (s, 3H, Me); m/z(%) 327 (M^+,14), 269(19), 268(100), 241(48), 208(14), 182(42), 181(45), 172(44), 156(48), 155(57), 140(12), 128(14), 127(55), 126(11) and 98(48).

Dimethyl 2,c-5-diphenyl-r-2, c-4-pyrrolidine dicarboxylate (13c). Obtained as colourless needles, m.p. 100-102°C from 40-60° petroleum ether-ether using $MgBr_2.Et_2O$ or Me_2NMgBr (Table 2). The product had identical spectroscopic data to that described previously.[11]

Imidazolidines (16) and (17) from Cycloadditions in the Presence of Metal Salts.

General Procedure. The imine (1mmol) and dipolarophile (4mmol) were dissolved in dry acetonitrile (50ml) and the appropriate metal salt (1.5mmol) added. The mixture was stirred at room temperature for the time shown in Table 3. The reaction was then quenched by the addition of saturated aqueous ammonium chloride (50ml), and extracted with methylene chloride (3x50ml). The combined extracts were washed with water, dried (anhy. Na_2SO_4) and evaporated under reduced pressure. The p.m.r. of the residue gave the isomer ratio (16):(17). The isomers were separated by flash chromatography (SiO_2) eluting with 1:1 v/v 40-60° petroleum-ether or by preparative t.l.c. (SiO_2) eluting with methylene chloride. Yields and isomer ratios are collected in Table 3.

Methyl 1-carbomethoxymethyl-2,5-di(2'-naphthyl)imidazolidine-4-carboxylate (16a) and (17a). [Found (mixed isomers): C, 73.65; H, 5.95; N, 6.05. $C_{28}H_{26}N_2O_4$ requires C, 74.00; H, 5.75; N, 6.15%).

(16a) Colourless oil. δ 8.04-7.49 (m, 14H, ArH), 5.44 (s, 1H, 2-H), 4.75 (d, 1H, J 6.5Hz, 5-H), 4.12 (d, 1H, 4-H), 3.81 and 3.53 (2xs, 2x3H, OMe) and 3.32 (dd, 2H, NCH_2); m/z(%) 454 (M^+,1) 238(32), 227(53) and 168(100).

(17a) Colourless rods from ether-pentane, m.p. 137-138°C. δ 8.19-7.53 (m, 14H, ArH), 5.34 (s, 1H, 2-H), 4.94 (d, 1H, J 9.3Hz, 5-H), 4.54 (d, 1H, 4-H), 3.57 (s, 3H, OMe), 3.36 (dd, 2H, J 17.5Hz, NCH_2) and 3.02 (s, 3H, OMe); m/z(%) 454 (M^+,1), 228(29), 227(69), 168(100) and 141(98).

Methyl 1-methyl-2,5-di(2'-naphthyl)imidazolidine-4-carboxylate (16b) and (17b). (Found mixed isomers: C, 78.50; H, 6.05; N, 6.90. $C_{26}H_{24}N_2O_2$ requires C, 78.75; H, 6.10; N, 7.05%).

(16b) Colourless needles from ether-pentane, m.p. 134°C. δ 7.48-8.03 (m, 14H, ArH), 4.65 (s, 1H, 2-H), 4.08 (d, 1H, J 7.5Hz, 5-H), 3.92 (d, 1H, 4-H), 3.75 (s, 3H, OMe) and 2.11 (s, 3H, NMe); ^{1}H NOEDSY(%) irradiation of 2-H effects an enhancement on 5-H(4%) but no enhancement on 4-H; m/z(%) 396 (M^+,2), 227(42), 170(100), 168(64) and 156(27); ν_{max} 3313, 3054, 2949, 1730, 1598, 825, 745 and 713 cm^{-1}.

(17b) Colourless needles from ether-pentane, m.p. 119-121°C (Found: C, 78.50; H, 6.05; N, 7.05%); δ 7.45-8.02 (m, 14H, ArH), 4.42 (s, 1H, 2-H), 4.29 (d, 1H, J 10Hz, 5-H), 4.09 (d, 1H, 4-H), 2.98 (s, 3H, OMe) and 2.08 (s, 3H, NMe); ^{1}H NOEDSY(%): irradiation of 4-H effects enhancements of the signals for 2-H(4.5%), 5-H(11.5%) and NMe(4%); m/z(%) 396 (M^+,2), 395(5), 170(100), 169(8) and 168(25); ν_{max} 3298, 3054, 2948, 1733, 1599, 895, 859, 819 and 747 cm^{-1}.

Methyl 1-benzyl-2,5-di(2'-naphthyl)imidazolidine-4-carboxylate (16c) and (17c). [Found (mixed isomers): C, 80.40; H, 5.85; N, 5.75. $C_{32}H_{28}N_2O_2$ requires C, 80.35; H, 5.95; N, 5.95%].

(16c) Viscous pale yellow oil. δ 7.83 (m, 10H, ArH), 7.47 (m, 4H, ArH), 7.06 (m, 5H, ArH), 4.95 (s, 1H, 2-H), 4.18 (d, 1H, J 7.5Hz, 5-H), 4.01 (d, 1H, 4-H), 3.67 (s, 2H, NCH_2) and 3.65 (s, 3H, OMe); m/z(%) 472 (M^+,0.5) 246(36), 245(59), 168(49), 141(54) and 91(100); ν_{max}(film) 3337, 3057, 2950, 2850, 1736, 1601, 908, 817 and 732 cm^{-1}.

(17c) Viscous pale yellow oil. δ 8.00 (m, 9H, ArH), 7.55 (m, 5H, ArH), 7.16 (m, 3H, ArH), 6.97 (m, 2H, ArH), 4.73 (s, 1H, 2-H), 4.38 (d, 1H, J 10Hz, 5-H), 4.16 (d, 1H, 4-H), 3.69 (s, 2H, NCH_2) and 2.94 (s, 3H, OMe); m/z(%) 472 (M^+,0.5), 365(17), 246(28), 245(55), 168(41), 141(50) and 91(100); ν_{max}(film) 3297, 3055, 2948, 2852, 1737, 1600, 859, 819 and 740 cm^{-1}.

Methyl 1-benzyl-2-(2'-naphthyl)-5-phenylimidazolidine-4-carboxylate (16d). Viscous pale yellow oil (Found: C,79.45; H,6.35; N,6.55. $C_{28}H_{26}N_2O_2$ requires C, 79.60; H, 6.20; N, 6.65%); δ 7.89-6.88 (m, 17H, ArH), 4.71 (s, 1H, 2-H), 3.97 (d, 1H, J 7.5Hz, 5-H), 3.86 (d, 1H, 4-H), 3.64 (s, 3H, OMe) and 3.60 (s, 2H, NCH_2); m/z(%) 295(15), 267(26), 246(39), 197(22), 117(22) and 91(100); ν_{max} 3370, 3040, 2960, 2805, 1740, 1602, 820, 755 and 700 cm^{-1}.

Methyl 1-Benzyl-2-phenyl-5-(2'-naphthyl)imidazolidine-4-carboxylate (16e). Viscous pale yellow oil (Found: C,79.70; H,6.05; N,6.90. $C_{28}H_{26}N_2O_2$ requires C, 79.60; H, 6.20; N, 6.65%); δ 8.31-6.91 (m, 17H, ArH), 4.95 (s, 1H, 2-H), 4.18 (d, 1H, J 7.5Hz, 5-H), 4.02 (d, 1H, 4-H) and 3.67 (br s, 5H, NCH_2 + OMe); m/z(%) 422 (M^+,1), 245(30), 196(24), 156(100), 127(95) and 91(61); ν_{max} 3350, 3050, 2975, 2920, 1735, 1600, 820, 740 and 700 cm^{-1}.

Thermal Fragmentation of Imidazolidines in the Presence of Dipolarophiles.

General Procedure. A mixture of imidazolidine (0.15mmol) and the dipolarophile (0.3mmol) in dry toluene (80ml) was boiled under reflux under an argon atmosphere for the time shown in Table 5. The solvent was then removed under reduced pressure and the residue crystallised from an appropriate solvent to afford the product. Yields are collected in Table 5. Diethyl 4-[5'-(2'-phenylthiazolyl)]-7-phenyl-6,8-dioxo-3,7-diazabicyclo [3.3.0]octane-2,2-dicarboxylate (25a, R=5-(2-phenylthiazolyl). Colourless cubes from ether-petroleum ether, m.p. 177-179°C (Found: C, 62.40; H, 4.70; N, 8.20. $C_{27}H_{25}N_3O_6S$ requires C, 62.45; H, 4.85; N, 8.10%); δ 7.88 and 7.34 (2xm, 11H, ArH + thiazolyl-H), 4.87 (d, 1H, J 8.1Hz, 4-H), 4.32 (m, 5H, 2x$\underline{CH_2}$Me + 1-H), 3.69 (dd, 1H, J 8.1 and 7.8Hz, 5-H) and 1.33 and 1.32 (2xt, 2x3H, $CH_2\underline{Me}$); m/z(%) 519 (M^+,22), 446(36), 346(34), 300(12) and 272(31); ν_{max} 3320,1780,1760,1730,1715,1500 and 1380 cm^{-1}. Diethyl 4,7-diphenyl-6,8-dioxo-3,7-diazabicyclo[3.3.0]octane-2,2-dicarboxylate (25a, R=Ph). Colourless rhombs from ether-petroleum ether, m.p. 133-135°C (Found: C, 66.00; H, 5.70; N, 6.25. $C_{24}H_{24}N_2O_6$ requires C, 66.05; H, 5.50; N, 6.40%); δ 7.29 (m, 10H, ArH), 4.52 (d,1H J 8Hz 4-H), 4.31 (m, 5H, 2x$\underline{CH_2}$Me + 1-H), 3.65 (dd, 1H, J 8 and 7.3Hz, 5-H), 3.01 (br s, 1H, exchangeable with D_2O, NH), and 1.33 and 1.30 (2xt, 2x3H, $CH_2\underline{Me}$); m/z(%) 436 (M^+,9), 364(23), 363(100), 144(12) and 117(11); ν_{max} 3340, 1765, 1740, 1715, 1600, 1500 and 1380 cm^{-1}. Diethyl 4-(4'-nitrophenyl)-7-phenyl-6,8-dioxo-3,7-diazabicyclo[3.3.0]octane-2,2-dicarboxylate (25a, R=p-$O_2NC_6H_4$). Pale yellow rods from ethanol, m.p. 216-218°C (Found: C, 59.80; H, 4.85; N, 9.00. $C_{23}H_{23}N_3O_8$ requires C, 59.90; H, 4.80; N, 8.75%); δ 8.2 and 7.65 (2xd, 2x2H, ArH), 7.31 (m, 5H, ArH), 4.59 (d, 1H, J 8Hz, 4-H), 4.36 (m, 5H, 2x$\underline{CH_2}$Me + 1-H), 3.70 (dd, 1H, J 8 and 7.3Hz, 5-H), 3.08(br s, 1H, exchangeable with D_2O, NH), and 1.35 and 1.33 (2xt, 2x3H, $CH_2\underline{Me}$); m/z(%) 481 (M^+,3), 409(24), 408(100) and 189(14); ν_{max} 3320, 1760, 1735, 1715, 1610, 1520, 1500, 1380 and 1350 cm^{-1}.

Diethyl 4(2'-pyridyl)-7-phenyl-6,8-dioxo-3,7-diazabicyclo[3.3.0]octane-2,2-dicarboxylate (25a, R=2-pyridyl). Colourless rods from ether-petroleum ether m.p. 132-135°C (Found: C, 63.35; H, 5.30; N, 9.70. $C_{23}H_{23}N_3O_6$ requires C, 63.15; H, 5.25; N, 9.60%); δ 8.63 (m, 1H, pyridyl-H), 7.75-7.10 (m, 8H, ArH + pyridyl-H), 4.59 (d, 1H, 9Hz, 4-H), 4.43-4.12 (m, 5H, 2x$\underline{CH_2}$Me + 1-H), 3.81 (dd, 1H, J 9 and 7.8Hz, 5-H), and 1.34 and 1.32 (2xt, 2x3H, $CH_2\underline{Me}$); m/z(%) 437 (M^+,6), 365(23), 364(100), 191(15), 171(23), 145(20) and 118(5); ν_{max} 3320, 1755, 1735, 1710, 1590 and 1380 cm^{-1}.

Diethyl 4(4'-methoxyphenyl)-7-phenyl-6,8-dioxo-3,7-diazabicyclo[3.3.0]octane-2,2-dicarboxylate (25a, R=p-MeOC_6H_4). Colourless plates from ethanol, m.p. 179-181°C (Found: C, 64.60; H, 5.75; N, 5.85. $C_{25}H_{26}N_2O_7$ requires C, 64.40; H, 5.60; N, 6.00%); δ 7.37 and 6.86 (2xd, 2x2H, ArH), 7.25 (m, 5H, ArH), 4.53-4.16 (m, 6H, 2x$\underline{CH_2}$Me, 1-H and 4-H), 3.77 (s, 3H, OMe), 3.60 (dd, 1H, J 9 and 7.8Hz, 5-H) and 1.33 and 1.30 (2xt, 2x3H, $CH_2\underline{Me}$); m/z(%) 466 (M^+,20), 394(23), 391(91), 293(100), 219(62) and 146(29); ν_{max} 3340, 1765, 1740, 1720, 1610, 1510 and 1380 cm^{-1}.

Diethyl 4(2'-furyl)-7-phenyl-6,8-dioxo-3,7-diazabicyclo[3.3.0]octane-2,2-dicarboxylate (25a, R=2-furyl). Colourless plates from ether-petroleum ether, m.p. 143-145°C (Found: C, 62.00; H, 5.40; N, 6.40. $C_{22}H_{22}N_2O_7$ requires C, 61.95; H, 5.15; N, 6.55%); δ 7.48-7.12 (m, 6H, ArH + furyl H), 6.37 (m, 2H, furyl H), 4.59 (dd, 1H, J 9 and 6Hz, 4-H), 4.46-4.1 (m, 5H, 2x$\underline{CH_2}$Me + 1-H), 3.67 (dd, 1H, J 9 and 7.8Hz, 5-H), 3.21 (br d, 1H, NH), and 1.32 and 1.39 (2xt, 2x3H, $CH_2\underline{Me}$), m/z(%) 426 (M^+,31), 354(36), 353(100), 253(53), 179(40), 134(26), and 107(21); ν_{max} 3325, 1750, 1730, 1710, 1600, 1495 and 1380 cm^{-1}.

Diethyl 4(2'-thienyl)-7-phenyl-6,8-dioxo-3,7-diazabicyclo[3.3.0]octane-2,2-dicarboxylate (25a, R=2-thienyl). Colourless rhombs from ether-petroleum ether, m.p. 148-150°C (Found: C, 59.75; H, 5.10; N, 6.05. $C_{22}H_{22}N_2OS$ requires C, 59.75; H, 5.00; N, 6.35%); δ 7.41-6.94 (m, 8H, ArH), 4.61 (dd, 1H, J 9 and 6.1Hz, 4-H), 4.45-4.13 (m, 5H, 2x$\underline{CH_2}$Me + 1-H), 3.61 (dd, 1H, J 9 and 7.8Hz, 5-H), 3.20 (br s, 1H, NH) and 1.32 and 1.30 (2xt, 2x3H, $CH_2\underline{Me}$); m/z(%) 442 (M^+,30), 370(23), 369(100), 269(34) and 195(27); ν_{max} 3340, 1760, 1725, 1600, 1500, 1380 and 1110 cm^{-1}.

Diethyl 4[5'-(2'-phenylthiazolyl)]-3-aza-6,8-dioxo-7-oxabicyclo[3.3.0]octane-2,2-dicarboxylate [25b, R=5-(2-phenylthiazolyl)]. Colourless cubes from benzene, m.p. 195-197°C (Found: C, 56.75; H, 4.65; N, 6.15. $C_{21}H_{20}N_2O_7S$ requires C, 56.75; H, 4.50; N, 6.30%); δ 7.90 and 7.40 (2xm, 6H, ArH + thiazolyl-H), 4.83 (dd, 1H, J 9 and 6Hz, 4-H), 4.51-4.13 (m, 5H, 2x$\underline{CH_2}$Me + 1-H), 3.79 (dd, 1H, J 9 and 7.8Hz, 5-H), 3.21 (br s, 1H, NH) and 1.36 and 1.31 (2xt, 2x3H, $CH_2\underline{Me}$); m/z(%) 444 (M^+,3), 371(26), 346(70)

272(100), 226(27) and 200(29); ν_{max} 3300, 1860, 1785, 1750, 1730, 1530, 1370 and 1080 cm^{-1}.

Diethyl 4-phenyl-3-aza-6,8-dioxo-7-oxabicyclo[3.3.0]octane-2,2-dicarboxylate (25b, R=Ph). Colourless rhombs from ether-petroleum ether, m.p. 147-149°C (Found: C, 59.75; H, 5.25; N, 3.90. $C_{18}H_{19}NO_7$ requires C, 59.85; H, 5.25; N, 3.90%); δ 7.36 (s, 5H, ArH), 4.48-4.23 (m, 6H, 2x$\underline{CH_2}$Me, 4-H and 1-H), 3.70 (dd, 1H, J 8.7 and 7.8Hz, 5-H), 3.03 (br s, 1H, NH) and 1.35 and 1.29 (2xt, 2x3H, $CH_2\underline{Me}$); m/z(%) 361(M^+,1), 289(52), 288(100), 216(98), 144(54) and 143(73); ν_{max} 3320, 1865, 1785, 1750, 1740, 1370 and 1075 cm^{-1}.

Diethyl 4(4'-nitrophenyl)-3-aza-6,8-dioxo-7-oxabicyclo[3.3.0]octane-2,2-dicarboxylate (25b, R=p-$O_2NC_6H_4$). Pale yellow needles from benzene, m.p. 213-215°C (Found: C, 52.95; H, 4.45; N, 6.85. $C_{19}H_{18}N_2O_9$ requires C, 53.20; H, 4.45; N, 6.90%); δ 8.27 and 8.19 (2xd, 2x2H, ArH), 4.57 (dd, 1H, J 8.7 and 6Hz, 4-H), 4.52-4.16 (m, 5H, 2x$\underline{CH_2}$Me and 1-H), 3.80 (dd, 1H, J8 and 8.7Hz, 5-H), 3.1 (br s, 1H, NH) and 1.36 and 1.32 (2xt, 2x3H, $CH_2\underline{Me}$); m/z(%) 407 (M+1,1), 334(20), 333(100), 261(21), 217(7) and 189(15); ν_{max} 3345, 1870, 1790, 1770, 1520, 1350 and 1080 cm^{-1}.

Tetraethyl 5-phenyl-1,2,4-triazolidine-1,2,3,3-tetracarboxylate (26a). Colourless rods from ethanol, m.p. 103-105°C (Found: C, 54.75; H, 6.20; N, 9.50. $C_{20}H_{27}N_3O_8$ requires C, 54.90; H, 6.20; N, 9.60%); δ ($CDCl_3$ 1 drop D_2O) 7.44 (m, 5H, ArH), 6.23 (s, 1H, 5-H), 4.13 (m, 8H, $\underline{CH_2}$Me) and 1.36, 1.28, 1.25 and 0.93 (4xt, 4x3H, $CH_2\underline{Me}$); m/z(%) 437 (M^+,12), 292(36), 263(28), 262(100), 189(31) and 117(29); ν_{max} 3320, 1740, 1720, 1250 and 1070 cm^{-1}.

Tetraethyl 5-(4'-nitrophenyl)-1,2,4-triazolidine-1,2,3,3-tetracarboxylate (26b). Pale yellow rods from ethanol, m.p. 89-91°C (Found: C, 49.80; H, 5.35; N, 11.65. $C_{20}H_{26}N_4O_{10}$ requires C, 49.80; H, 5.40; N, 11.60%); δ ($CDCl_3$ + 1 drop D_2O) 8.19 and 7.76 (2xd, 2x2H, ArH), 6.35 (s, 1H, 5-H), 4.15 (m, 8H, $\underline{CH_2}$Me), and 1.35, 1.30, 1.24 and 0.91 (4xt, 4x3H, $CH_2\underline{Me}$); m/z(%) 482 (M^+,5), 365(34), 338(27), 337(100), 308(23) and 307(85); ν_{max} 3300, 1750, 1725, 1520, 1345, 1255 and 1065 cm^{-1}.

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