Lewis Acid-promoted Conjugate Reduction of α,β-Unsaturated Carbonyl Compounds by 2-Phenylbenzothiazoline (2-Phenyl-2,3-dihydrobenzothiazole)

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Reduction of various α,β-unsaturated ketones (**3a—g**) and (**4a—d**) in methanol by the benzothiazoline (**1**) in the presence of aluminium chloride gives, in all cases, the corresponding saturated ketones (**5a—g**) and (**6a—d**) without any of the unsaturated or saturated alcohol. Reduction of α,β-unsaturated esters (**7a,b**) similarly gives the saturated esters (**9a,b**), while reaction of cinnamaldehyde (**8**) with compound (**1**) does not occur at all. Among the Lewis acids examined, aluminium chloride gives the best results. Reduction of 2′-azachalcone (**21**) with 2-phenyl[2-^{2}H]benzothiazoline reveals that, in the reduction product, the deuterium atom is located at the β-position with respect to the carbonyl group. The result obtained from the reduction of the same substrate with compound (**1**) in methan[^{2}H]ol shows that no incorporation of a hydrogen atom from the solvent takes place and suggests (indirectly) that the introduced hydrogen atom at the α-position of the product comes from the benzothiazoline (**1**). The reaction of (*Z*)-1,2-dibenzoyl-1,2-diphenylethylene (**30**) with compound (**1**) in the presence of aluminium chloride stereospecifically yields *meso*-1,2-dibenzoyl-1,2-diphenylethane (**31**). This shows that the transfer of two hydrogens from compound (**1**) to the carbon–carbon double bond of the enone proceeds *via cis*-addition. Experiments with ethyl phenylpropiolate (**28**) also support *cis*-reduction for the present conjugate reduction. These results are interpreted in terms of a mechanism involving synchronous transport of a pair of hydrogens from the benzothiazoline (**1**); *i.e.*, a cyclic addition of the two hydrogens either in exact or nearly exact concurrence.

The development of methods applicable to the selective reduction of organic functional groups has been one of considerable interest to synthetic chemists. However, despite much work in this field, little attention has been given to the use of heterocycles having hydrogen-donating ability as practical reducing agents for such selective reduction. NAD(P)H coenzyme-model reduction with 1,4-dihydropyridine derivatives such as *N*-alkylated 1,4-dihydronicotinamides, their benzo-analogues, or 3,5-bisethoxycarbonyl-1,4-dihydro-2,6-dimethylpyridine (so-called Hantzsch ester) have attracted much attention in recent years and have been extensively studied with a wide variety of substrates. Although, more recently, several reports[1] have appeared dealing with the use of 1,4-dihydropyridine as a reducing agent from a synthetic viewpoint, the reactions with NAD(P)H-model compounds have, so far, been investigated mainly because of biological, biomimetic, or mechanistic interests. The practical capabilities of such dihydropyridines as reducing agents in organic synthesis seem to be small because of their low reactivity and their instability.[2]

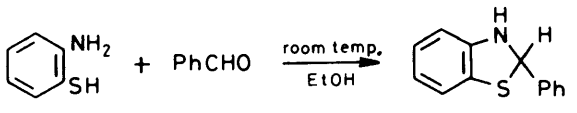
During our study of the synthetic utilities of heterocyclic hydrogen donors, we have recently shown that 2-phenylbenzimidazoline† is a useful and convenient reducing agent for the selective reduction of carbon–carbon double bonds of α,β-unsaturated dinitriles[3] or 1-nitro-2-arylalkenes.[4] On the other hand, chemoselective hydrogenation of carbon–carbon double bonds of α,β-unsaturated carbonyl compounds has long been a desired synthetic transformation. Although there are several methods available to bring about such conversions, they have not always afforded satisfactory results. In our previous communication,[5] we reported the preliminary results of a novel and regioselective reduction of α,β-unsaturated carbonyl compounds using 2-phenylbenzothiazoline‡ as a reducing agent. In the present paper, we report details of a Lewis acid-promoted conjugate reduction of various α,β-unsaturated carbonyl compounds by the benzothiazoline (**1**), disclose the scope, limitations, and general applicability of this method, and show the mechanistic and stereochemical features of the transfer of a pair of hydrogens from compound (**1**) in these reactions.

† 2-Phenyl-2,3-dihydrobenzimidazole

‡ 2-Phenyl-2,3-dihydrobenzothiazole

Results and Discussion

Preparation and Properties of the Reducing Agent.—In contrast to 2-substituted benzimidazolines, which should be prepared *in situ* from *o*-phenylenediamine and aldehydes in an appropriate solvent because they are unstable intermediates and rapidly oxidize automatically to the corresponding benzimidazoles in the absence of an appropriate hydrogen accepter,[6] the benzothiazoline (**1**) can be easily prepared and nearly quantitatively isolated by the reaction of *o*-amino(thiophenol) with benzaldehyde in ethanol [equation (1)]. Compound (**1**)



(1) (1)

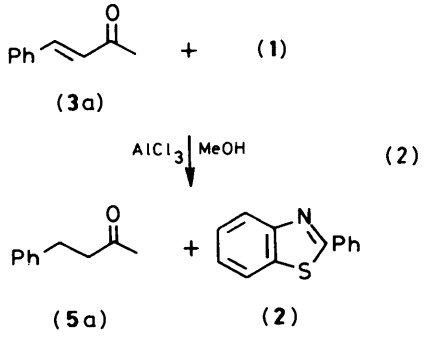
exists as light yellow needles which are easily handled; it is stable in air but is gradually oxidized to 2-phenylbenzothiazole (**2**) on prolonged heating.

Scope, Limitations, and General Applicability.—We chose benzylideneacetone (**3a**) as a model compound for preliminary assays of the present study. As shown in Table 1, the reduction of the enone (**3a**) proceeded in only 2% yield without a catalyst. We have discovered, however, that the reduction can be effectively performed in the presence of a Lewis acid in dry methanol at 80 °C. In the reaction system employing aluminium chloride, the conjugate reduction products, benzylacetone (**5a**) and the benzothiazole (**2**), were isolated in 87 and 98% yield respectively

Table 1. Catalytic effect of Lewis acids on the yield of benzylacetone (**5a**)[a]

Lewis acid	Molar proportions (**3a**):(**1**):Lewis acid	Yield of (**5a**) (%)[b]
None	1:1:0	2
$ZnCl_2$	1:1:1	6
$FeCl_3$	1:1:1	43
$SnCl_4$	1:1:1	69
$AlCl_3$	1:1:1	100
$AlCl_3$	1:1:0.5	49

[a] All the reactions were carried out in methanol at 80 °C for 3 h. [b] Determined by g.l.c.

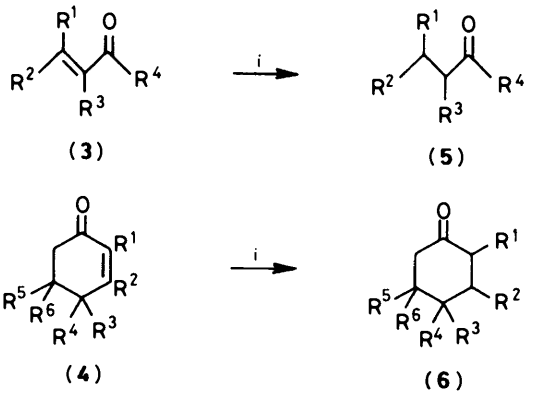


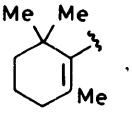
Compounds (**3**)—(**6**) are defined in Scheme 1

after a 3 h reaction followed by chromatography over a short column of silica gel [equation (2)]. The formation of other products could not be detected. This result shows that the carbon–carbon double bond of the enone is reduced by compound (**1**) with complete regioselectivity and the compensating oxidation is that of the benzothiazoline (**1**) to the benzothiazole (**2**). Among the solvents tested, methanol gave the best results. The use of aluminium chloride and enone in equimolar amounts is sufficient to promote the reaction, while the use of 0.5 mol equiv. of aluminium chloride (with respect to the enone) gave the reduced product in 49% yield. This shows that the present conjugate reduction requires a stoicheiometric amount of Lewis acid. Regarding the investigation of the catalytic efficiency of other Lewis acids, Table 1 indicates that the catalytic efficiency of a Lewis acid is proportional to its efficiency [7] to form a complex with a carbonyl group. Thus, a Lewis acid can be regarded as an electrophilic activator to polarize a carbon–carbon double bond due to the formation of a complex with a carbonyl group of the enone.

We next demonstrate the general applicability of the present method to a variety of α,β-unsaturated ketones (Scheme 1).

The results for the reduction of linear enones (**3**) are given in Table 2. Generally, the reduction of linear enones by the present method can be performed easily, to give good yields of the corresponding saturated ketones. However, the reduction of 3-methyl-4-phenylbut-3-en-2-one (**3e**) was unexpectedly sluggish and gave product (**5e**) in low yield. β-Ionone (**3f**), corresponding to an α,β,γ,δ-unsaturated carbonyl compound, was selectively reduced to dihydro-β-ionone (**5f**) in quantitative yield, and the γ,δ-double bond in the cyclohexene ring was not influenced at all. 1,2-Dibenzoylethylene (**3c**), corresponding to an α,β-unsaturated diketone, was also reduced without difficulty to dione (**5c**) in nearly quantitative yield. In all cases, the conjugate reduction products were obtained with complete selectivity, and none of the unsaturated alcohol, corresponding to the 1,2-reduction product, or saturated alcohol was detected. It should be noted that the rate of the reduction is influenced by the environment around the double bond. The reduction of a



(**3**), (**5**) **a**; $R^1 = R^3 = H$, $R^2 = Ph$, $R^4 = Me$
b; $R^1 = R^3 = H$, $R^2 = R^4 = Ph$
c; $R^1 = R^3 = H$, $R^2 = COPh$, $R^4 = Ph$
d; $R^1 = R^2 = R^4 = Me$, $R^3 = H$
e; $R^1 = H$, $R^2 = Ph$, $R^3 = R^4 = Me$
f; $R^1 = R^3 = H$, $R^2 =$  , $R^4 = Me$

g; $R^1 = Ph$, $R^2 = H$, $R^3R^4 = -[CH_2]_4-$

(**4**), (**6**) **a**; $R^1 = R^2 = R^3 = R^4 = R^5 = R^6 = H$
b; $R^1 = R^3 = R^4 = H$, $R^2 = R^5 = R^6 = Me$
c; $R^1 = Me$, $R^2 = R^3 = R^4 = R^5 = R^6 = H$
d; $R^1 = R^5 = R^6 = H$, $R^2R^3 = -[CH_2]_4-$

Scheme 1. *Reagents:* i, (**1**), $AlCl_3$, MeOH

linear enone possessing disubstitution at the α- or β-carbon of the enone was more sluggish than that of α- or β-monosubstituted enones, including compounds (**3c**) and (**3f**), and required a longer reaction time.

In the same manner, we examined the reduction of a series of cyclic enones (**4**). The results are given in Table 3. The reduction of cyclic enones is generally slower than that of linear enones, but in this case afforded satisfactory yields of saturated cyclic ketones. In contrast to the internal olefins, 2-benzylidenecyclohexanone (**3g**), which has an external double bond conjugated with a carbonyl group, was rapidly reduced to 2-benzylcyclohexanone (**5g**) in nearly quantitative yield. As in the case of linear enones, only conjugate reduction products were detected in these reactions. As to the stereochemistry of the reduction, the octalone (**4d**) was converted into the decalone (**6d**). The stereochemistry of this reaction is comparable to hydrogenation over palladium catalysts [8] or reduction with complex copper hydride reagents.[9] Hydrogenation or copper hydride reduction of the octalone (**4d**) yielded a mixture of isomeric decalones (**6d**), with the *cis*-isomer predominating. The reduction of the octalone (**4d**) by the present method produced a *cis*:*trans* ratio of 65:35, which was somewhat less specific than in catalytic hydrogenation or complex copper hydride reduction.

In conclusion, the conjugate reduction of a variety of α,β-unsaturated ketones by the benzothiazoline (**1**) in methanol in the presence of aluminium chloride can be performed in good yield with complete regiospecificity and without side-reactions. The relative reactivities of the enones were found to decrease in the order α,β-monosubstituted linear enone > cyclic ketone conjugated with external double bond > α-monosubstituted-β-disubstituted linear enone > common cyclic enone > α-disubstituted-β-monosubstituted linear enone.

The conjugate reduction of an α,β,-unsaturated ester (**7**) and a

Table 2. Conjugate reduction of linear enones (**3**) with the benzothiazoline (**1**) in the presence of aluminium chloride[a]

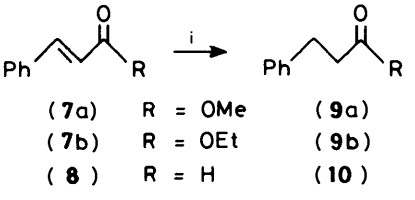
Enone	Reaction time (h)	Yield of (**5**) (%) G.l.c.	Yield of (**5**) (%) Isolated[b]	M.p. (°C) or b.p. (°C/mmHg)	Lit. m.p. (°C) or b.p. (°C/mmHg)	*m/z* (M^+)
(**3a**)	3	100	89	115—118/16	110—112/12[c]	148
(**3b**)	3	90	71	72.5—73.5	72[d]	210
(**3c**)	3	100	91	145—146	142—143[e]	238
(**3d**)	24	76	63	45.5—46/80	117/760[f]	100
(**3e**)	24	26	16	104—105/18	102—104/12[c]	162
(**3f**)	3	100	98	105—107/3	122—122.5/12[g]	194
(**3g**)	3	92	90	140—141/1	142/1[h]	

[a] All the experiments were performed in methanol at 80 °C with molar proportions of (**1**):aluminium chloride:enone (**3**) of 1.2:1.2:1 [b] Yield of pure product after isolation by s.c.c. on silica gel. [c] A. Citterio and E. Vismara, *Synthesis*, 1980, 291. [d] D. R. G. Brimage, R. S. Davidson, and P. F. Lambeth, *J. Chem. Soc. C*., 1971, 1241. [e] J. P. Schaeter, *J. Org. Chem*., 1960, **25**, 2027. [f] G. Dupont, *Bull. Soc. Chim. Fr*., 1936, **3**, 1021. [g] A. Caliezi and H. Schinz, *Helv. Chim. Acta*, 1950, **33**, 1129. [h] R. B. Woodward, F. Sondheimer, D. Taub, K. Heusler, and W. M. Mclamore, *J. Am. Chem. Soc*., 1952, **74**, 4223.

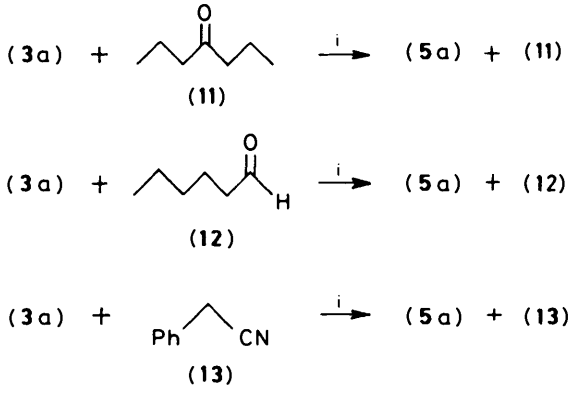
Table 3. Conjugate reduction of cyclic enones (**4**) with the benzothiazoline (**1**) in the presence of aluminium chloride[a]

Enone	Reaction time (h)	Yield of (**6**) (%) G.l.c.	Yield of (**6**) (%) Isolated[b]	M.p. (°C) or b.p. (°C/mmHg)	Lit. m.p. (°C) or b.p. (°C/mmHg)	*m/z* (M^+)
(**4a**)	24	55	26	74—74.5/45	153—156/760[e]	98
(**4b**)	24	65	50	54—56/12	201—203/750[f]	140
(**4c**)	24	50	25	46.5—47/12	155—164/760[g]	122
(**4d**)	24	52[c]	11[c]	175—176.5 (*cis*)[d]	175—176[h]	
				178.5—180 (*trans*)[d]	178—179[h]	

[a] All the experiments were performed in methanol at 80 °C with molar proportions of (**1**):aluminium chloride:enone (**4**) of 1.2:1.2:1 [b] Yield of pure product after isolation by s.c.c. on silica gel. [c] Yield of isomeric mixture; *cis*:*trans* ratio 65:35 (g.l.c. analysis on Silicon OV-7). [d] M.p. of 2,4-dinitrophenylhydrazone derivative. [e] F. S. Bridson-Jones, G. D. Buckley, L. H. Cross, and A. P. Driver, *J. Chem. Soc*., 1951, 2999. [f] A. Skita and W. A. Meyer, *Ber. Dtsch. Chem. Ges*., 1912, **45**, 3589. [g] P. D. Bartlett and R. H. Rosenwald, *J. Am. Chem. Soc*., 1934, **56**, 1990. [h] See ref. *h*, Table 2.



Scheme 2. *Reagents:* i, (**1**), $AlCl_3$, MeOH



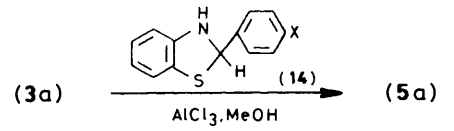
Scheme 3. *Reagents:* i, (**1**), $AlCl_3$, MeOH

similar aldehyde (**8**) were also examined under the optimum conditions (Scheme 2). Methyl cinnamate (**7a**) and ethyl cinnamate (**7b**) were less effectively reduced to the corresponding 3-phenylpropionate (**9a**,**b**) (18 and 19% yield, respectively). However, the conjugate reduction of cinnamaldehyde (**8**) to the expected saturated aldehyde, 3-phenylpropanal (**10**), did not occur at all. These results may show that the present method is inapplicable to the conjugate reduction of α,β-unsaturated esters and similar aldehydes.

It is interesting and important to note the functional selectivity of the present reduction. Thus, mixed reduction of the enone (**3a**) with ketone (**11**), aldehyde (**12**), or nitrile (**13**) in the presence of 2 mol equiv. of aluminium chloride to the enone was demonstrated at 80 °C for 3 h as shown in Scheme 3. In all cases, the ketone (**5a**) was obtained in quantitative yield with complete functional selectivity. On the other hand, reductions in the presence of 1 mol equiv. of aluminium chloride under similar conditions produced low yields of ketone (**5a**). These results show that aluminium chloride is required in an amount equimolar with the co-ordinatable groups such as carbonyl or nitrile existing in the reducing system to promote the reduction. In addition, we have found that other functional groups such as carboxylic ester, acid, nitro, isolated C=C, or isolated C≡C are inert to the present reducing system. Since functional selectivity is one of the factors which permit estimation of the value of reducing agents, these selective properties may enhance the utility of the present reduction method.

Mechanism.—The substituent effect of group X on the reducing ability of the benzothiazoline (**1**) was studied in order to elucidate the mechanism of the present conjugate reduction. For this purpose, the reduction of the enone (**3a**) with 1.2 equiv. of substituted thiazolines (**14**) and aluminium chloride was monitored at 80 °C. As shown in Table 4, when compound (**1**) was substituted by an electron-donating group, the rate of the reduction increased. On the other hand, the rate decreased with an increase in electron-withdrawing ability of the substituent. Since it is reasonable to expect that these substituents influence mainly the movement of a hydrogen atom at the C-2 position, these results indicate that the reduction most likely consists of the transfer of a hydrogen atom at the C-2 position as hydride and

Table 4. Reactivity of some *p*-substituted phenyl benzothiazolines (**14**) in the reduction of benzylideneacetone (**3a**) in the presence of aluminium chloride[a]



Benzothiazoline	X	Reaction times and yields (%)[b] 1 h	2 h	3 h	4 h
(**14a**)	OMe	89	100		
(**1**)	H	45	100		
(**14b**)	Cl	43	59	69	73
(**14c**)	NO_2	41	59	68	69

[a] All the reactions were carried out at 80 °C with molar proportions of benzothiazoline:aluminium chloride:enone (**3a**) of 1.2:1.2:1.. [b] Determined by g.l.c.

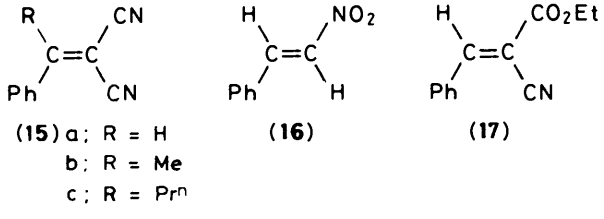
Table 5. Reduction of highly electron-deficient olefins by the benzothiazoline (**1**)[a]

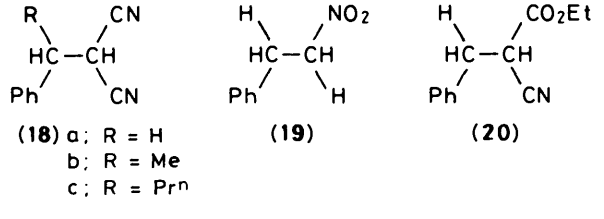
Olefin	Solvent	Reaction time (h)	Product	Yield (%)[b]
(**15a**)	EtOH	5	(**18a**)	98[c]
(**15b**)	Bu^{n}OH	24	(**18b**)	97[d]
(**15c**)	Bu^{n}OH	24	(**18c**)	93[d]
(**16**)	Bu^{n}OH	24	(**19**)	80[d]
(**17**)	Bu^{n}OH	8	(**20**)	92[c]

[a] All the reactions were carried out at the reflux temperature of the solvent. [b] Yield of isolated, pure product. [c] A molar ratio of (**1**):olefin of 1.2:1 was used. [d] A molar ratio of (**1**):olefin of 2.4:1 was used.

that the process involving the movement of a hydrogen at the C-2 carbon is probably the major rate-determinating step of the reduction.

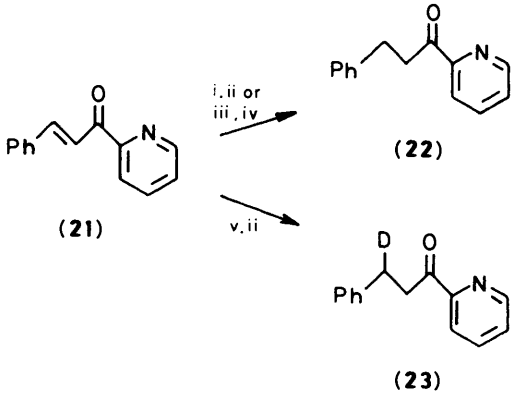
Evidence of hydride reduction is also seen in the results of the reduction of the selected olefins (**15**)—(**17**). These highly





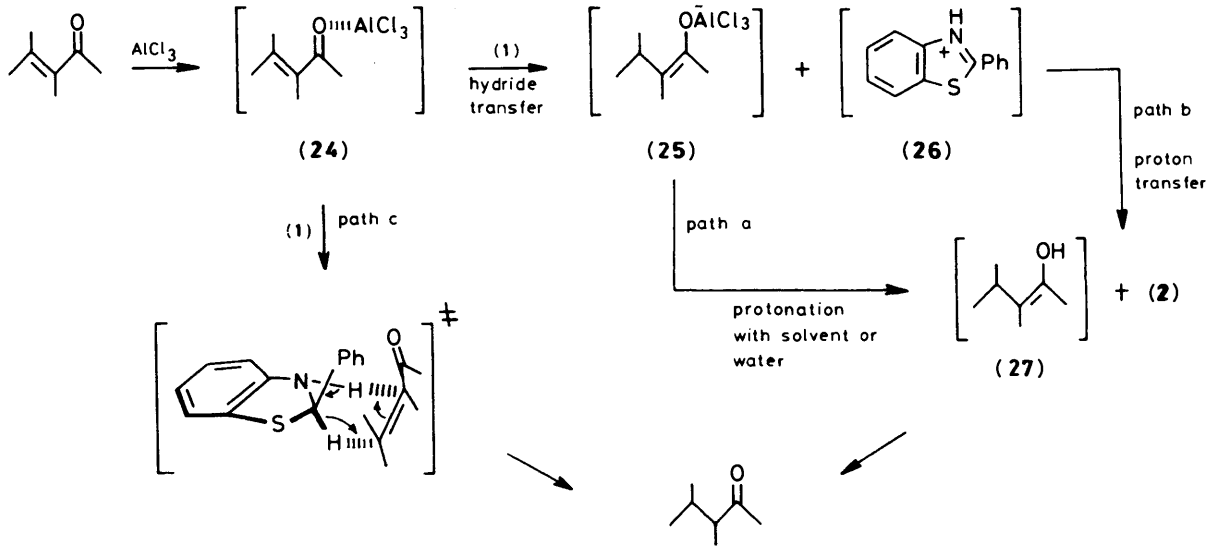
electron-deficient C=C double bonds conjugated with CN, NO_2, or CO_2Et were reduced by the benzothiazoline (**1**) in good yield without the aid of a Lewis acid (Table 5). These results are clearly understood if we accept the mechanism involving a hydride transfer, and support a mechanism in which the α,β-unsaturated carbonyl system is electrophilically activated to enable it to accept a hydride by co-ordination of the carbonyl oxygen with a Lewis acid.

In an attempt to determine the destination of a hydrogen atom at the C-2 carbon of compound (**1**), we reduced 2'-azachalcone (**21**) with the 2-deuteriated benzothiazoline

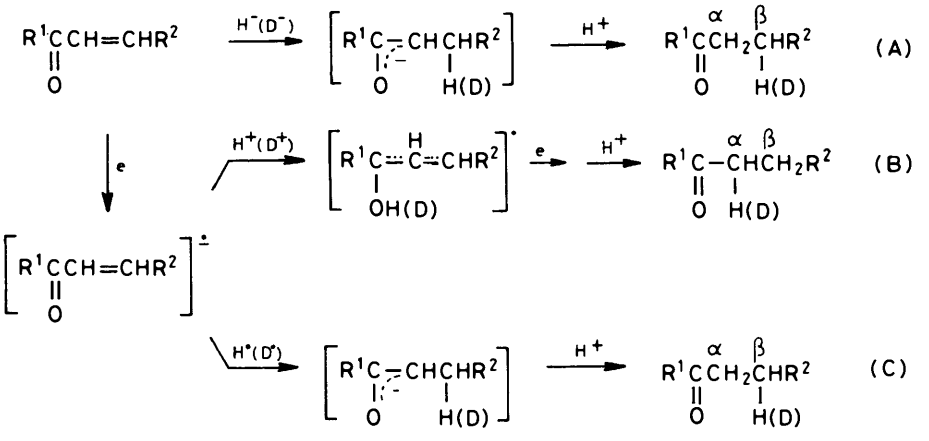


Scheme 4. *Reagents:* i, (**1**), $AlCl_3$, MeOH; ii, water; iii, (**1**), $AlCl_3$, MeOD; iv, D_2O; v, [2-^{2}H]-(**1**), $AlCl_3$, MeOH

[2-^{2}H]-(**1**) which can be easily prepared from deuteriated benzaldehyde according to equation 1 (Scheme 4). The product of this reaction was found to be the saturated ketone (**23**) containing one deuterium atom at the β-carbon to the carbonyl group. This result supports our hypothesis that the hydrogen atom at C-2 carbon of compound (**1**) transfers to the β-carbon of the substrate as a hydride, because the carbon at the C-2 position is very electrophilic due to the formation of the complex (**24**) between aluminium chloride and the carbonyl group of the enone (Scheme 5). At this stage, three possible reaction mechanisms for the present conjugate reduction of α,β-unsaturated carbonyl compounds by the benzothiazoline (**1**) can be proposed as shown in Scheme 5. They involve a hydride transfer followed by protonation of the enolate (**25**) by solvent or by quenching with water (path a); a sequential transfer of a pair of hydrogens from the benzothiazoline (**1**) *via* the intermediates (**25**) and (**26**) (path b); and a cyclic addition of two hydrogens from compound (**1**) (path c). In paths a and b, the initial reduced product is thought to be the enol (**27**) which tautomerizes rapidly to the saturated ketone. When azachalcone (**21**) was reduced by compound (**1**) in methan[^{2}H]ol, the non-deuteriated ketone (**22**) was obtained in 90% yield after work-up with D_2O (Scheme 4). This indicates that no incorporation of a hydrogen atom from either the solvent or from the water in the work-up takes place, and suggests (indirectly) that the hydrogen atom at the α-position of the product comes from the benzothiazoline (**1**). Thus, a mechanism involving protonation (deuteriation) of the enolate (**25**) by (labelled) solvent or quenching water, which would (for the labelled case) incorporate a deuterium label at the α-carbon, is excluded by the fact that no deuterium label at the α-position of the product was detected. Accordingly, a pathway involving the transfer of a pair of hydrogens from compound (**1**) (*i.e.* path b or path c) is operative in the reaction, and these processes conform to the driving force of the formation of the stable benzothiazole (**2**). Recently, the mechanism of hydride-equivalent transfer in reductions with 1,4-dihydropyridine derivatives has been extensively discussed, and it has been proposed in some cases[10] that the reduction most likely consists of an initial electron transfer followed by the transfer of a hydrogen nucleus or radical. Although the initial hydride transfer shown in Scheme 5 may be viewed as simply a one-step hydride transfer (mechanism A), schemes involving sequential transfers of e + H^+ (mechanism C) and e + H^+ + e (mechanism B) are also possible in theory (Scheme 6). In considering mechanisms A



Scheme 5.

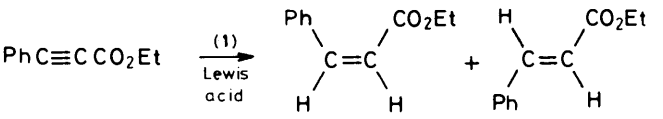


Scheme 6.

and C, it is expected that they would insert the hydride at the β-position in the product after completion of the reaction. On the other hand, mechanism B should give the saturated ketone in which hydride introduction would be expected at the α-carbon. Thus, in the light of the observation in the above-mentioned experiment with [2-^{2}H]-(**1**), mechanisms A and C are both candidates for the initial hydride transfer shown in Scheme 5.

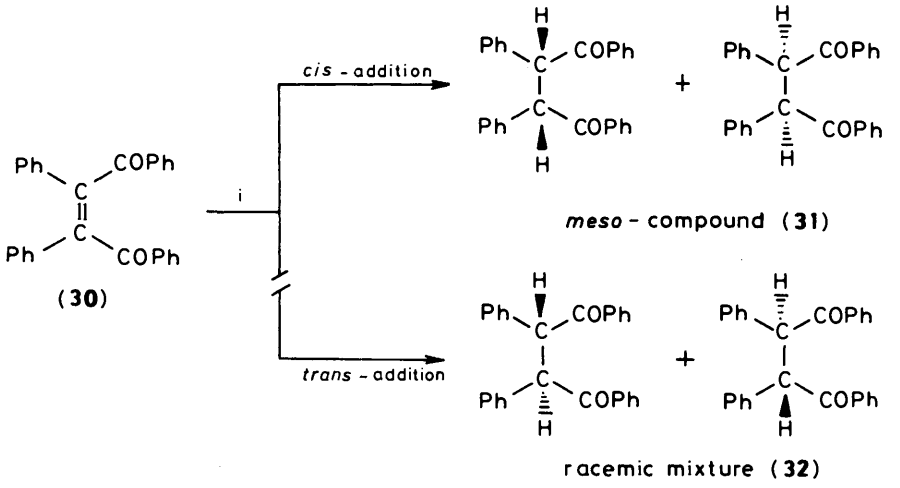
We consider that only the stereochemistry of the transfer of a pair of hydrogens from the benzothiazoline (**1**) to the carbon–carbon multiple bond of an α,β-unsaturated carbonyl system can distinguish between path b and path c. For this purpose, ethyl phenylpropiolate (**28**) was reduced by the benzothiazoline (**1**) in the presence or absence of a Lewis acid in methanol (Table 6). Interestingly, this reaction produced ethyl (*Z*)-cinnamate (**29**) in excellent yield with high selectivity. This result suggests that the transfer of a pair of hydrogens from compounds (**1**) to the substrate proceeds in a *cis*-addition mode. In contrast to the reduction of ethyl cinnamate, the reduction of this ester is relatively easy, and the low reactivity of compound (**7b**) allows this partial reduction. A change of Lewis acid does not change the selectivity of the reduction, but the reaction with aluminium chloride in methanol gave the best results in terms of both yield and selectivity. However, and remarkably, reduction in tetrahydrofuran gave ethyl (*E*)-cinnamate (**7b**), thus showing reverse

Table 6. Partial conjugate reduction of ethyl phenylpropiolate (**28**) by the benzothiazoline (**1**) in the presence of Lewis acid[a]



Lewis acid	Solvent	(29) + (7b) Yield (%)[b]	(29):(7b)[b]
$AlCl_3$	MeOH	88	96:4
$AlCl_3$	THF	98	15:85
$ZnCl_2$	MeOH	76	94:6
None	MeOH	80	91:9

[a] All the reactions were carried out at the reflux temperature of the solvent, with the molar ratio of (**1**):Lewis acid:(**28**) of 1:1:1. [b] Determined by g.l.c.



Scheme 7. *Reagents:* i, (1), $AlCl_3$, MeOH

selectivity. The reason for this extreme solvent effect has not yet been elucidated.

In order to determine directly the stereochemistry of the transfer of a pair of hydrogens from compound (**1**) to the carbon–carbon double bond of α,β-unsaturated carbonyl compounds, we tried the reduction of (*Z*)-1,2-dibenzoyl-1,2-diphenylethylene (**30**) by compound (**1**) in the presence of aluminium chloride. As expected, as shown in Scheme 7, this reaction produced, stereospecifically, *meso*-1,2-dibenzoyl-1,2-diphenylethane (**31**), and the racemic product (**32**) corresponding to *trans*-addition was undetectable. This result shows clearly that transfer of a pair of hydrogens from compound (**1**) to the enone proceeds *via cis*-addition, and supports the validity of the *cis*-reduction mechanism for the present conjugate reduction.

We are now in a position to discuss whether the transfer of a pair of hydrogens from the benzothiazoline (**1**) to the enones proceeds through path b or path c. From the fact that reduction proceeds in a *cis*-addition mode, we believe that the hydrogen shift of the present conjugate reduction is a synchronous transport of a pair of hydrogens; *i.e.*, that the reduction is a cyclic addition of two hydrogens in either exact or nearly exact concurrence. Finally, mechanistic resemblance of the present reduction to the Diels–Alder reaction or the Ene reaction should be noted. The latter reactions are widely accepted as proceeding through a cyclic transition state either in exact or nearly exact concurrence and it is well known that aluminium chloride can bring about remarkable acceleration of these reactions according to a mechanism similar to path c in Scheme 5.[11] These literature data are in accord with our conclusion, and support the validity of path c, including the marked catalysis by aluminium chloride.

Experimental

M.p.s were recorded on a Yanagimoto micro melting point apparatus and are uncorrected. ^{1}H N.m.r. spectra were measured on a JEOL JNM-PMX-60 spectrometer at 60 MHz and chemical shifts are given in δ-values from tetramethylsilane as internal standard. I.r. spectra were recorded on a JASCO A-202 spectrophotometer. Mass spectra were obtained on a JMS-QH100 GC-Mass spectrometer. Gas chromatographic analyses were carried out on a Simadzu Gas chromatograph GC-6AM equipped with a hydrogen flame-ionization detector using glass columns (1.5 m) packed with 2% Silicon OV-7 on Uniport HP (60—80 mesh). The yields by quantitative g.l.c. were measured on the same columns by the internal standard method, using n-amylbenzene as an internal standard. Silica gel (Wakogel C-300) was used for short-column chromatography (s.c.c.) and t.l.c. was carried out on Merck pre-coated silica gel plates (Merck Silica gel $60F_{254}$).

Materials.—Benzylideneacetone (**3a**), b.p. 110—112 °C/4.5 mmHg; m.p. 40—42 °C (lit.,[12] b.p. 123—128 °C/8 mmHg; m.p. 40—42 °C), benzylideneacetophenone (**3b**), m.p. 55—57 °C (lit.,[13] 55—57 °C), 2-benzylidenecyclohexanone (**3g**), m.p. 52—54 °C (lit.,[14] 52—53 °C), and 2-cinnamoylpyridine (**21**), m.p. 71—72 °C (lit.,[15] 71—72 °C) were prepared by aldol condensation according to the reported procedures. 4a-Methyl-4,4a,5,6,7,8-hexahydronaphthalen-2(3H)-one (**4d**), b.p. 109—111 °C/1 mmHg (lit.,[16] 112—115 °C/5 mmHg) was prepared by acid-catalysed Robinson annelation according to the method of Heathcock *et al.* 2-Methylcyclohex-2-enone (**4c**), b.p. 64.5—65.5 °C/16 mmHg (lit.,[17] 83—85.5 °C/35 mmHg), and ethyl phenylpropiolate (**28**), b.p. 120—129 °C/5 mmHg (lit.,[18] 96—108 °C/1 mmHg), were prepared by the reported procedures. *Z*-1,2-Dibenzoyl-1,2-diphenylethylene (**30**), m.p. 219—221 °C (lit.,[19] 211—213 °C) was obtained by the acid-catalysed ring-opening reaction of tetraphenylfuran according to the method of Lutz *et al.* All other α,β-unsaturated carbonyl compounds were commercial materials which were purified by distillation. Lewis acids were commercially available and were used without purification. Benz[^{2}H]aldehyde, b.p. 85—86 °C/28 mmHg (lit.,[20] 77—78 °C/27 mmHg), was prepared *via* deuteriation of 2-lithio-2-phenyl-1,3-dithiane with D_2O, and was pure by ^{1}H n.m.r. spectroscopy; no aldehyde proton signal was detected. Other reagents and solvents were commercially supplied and purified by the usual methods.

Preparation of 2-Phenylbenzothiazoline (**1**).—Benzaldehyde (10.6 g, 0.1 mol) was added to a solution of *o*-amino(thiophenol) (12.5 g, 0.1 mol) in ethanol (20 ml) and the mixture was stirred at room temperature. After *ca.* 30 min, pale yellow needles separated from the reaction mixture, which was then stirred for another 10 min. The resulting needles were collected by filtration and recrystallized from ethanol to give the pure thiazoline (**1**) (20.1 g, 94%) as pale yellow needles, m.p. 77 °C (lit.,[21] 77 °C); $\nu_{max.}$ 3 390, 1 580, 1 300, 740, and 700 cm^{-1}; δ($CDCl_3$) 4.19 (1 H, br, NH), 6.26 (1 H, s, 2-H), 6.45—6.95 (4 H, m, ArH), and 7.03—7.55 (5 H, m, Ph) (Found: C, 73.2; H, 5.1; N, 6.45. Calc. for $C_{13}H_{11}NS$: C, 73.20; H, 5.20; N, 6.57%).

Preparation of 2-Phenyl[2-^{2}H]*benzothiazoline.*—Benz[^{2}H]-aldehyde (0.32 g, 3 mmol) was added to a solution of *o*-amino (thiophenol) (0.38 g, 3 mmol) in ethanol (3 ml) and the mixture

was stirred for 1 h at room temperature. The resulting needles were collected by filtration and recrystallized from ethanol to give pure title benzothiazoline (0.57 g, 89%) as pale yellow needles, m.p. 77 °C; δ($CDCl_3$) 4.19 (1 H, br, NH), 6.39—6.95 (4 H, m, ArH), and 7.05—7.45 (5 H, m, Ph). The n.m.r. singlet at δ 6.26 due to the proton at C-2 could not be detected at all.

Preparation of Benzothiazolines (**14a—c**).—*p*-Chlorobenzaldehyde (0.70 g, 5 mmol) was added to a solution of *o*-amino(thiophenol) (0.63 g, 5 mmol) in ethanol (10 ml) and the mixture was stirred for 40 min at room temperature. The resulting needles were collected by filtration, washed with cold ethanol, and then dried *in vacuo* to give 2-(p-*chlorophenyl*)*benzothiazoline* (**14b**) as needles (1.24 g, 100%), m.p. 81—83 °C; $\nu_{max.}$ 3 345, 1 085, and 752 cm^{-1}; δ($CDCl_3$) 3.78 (1 H, br, NH), 6.16 (1 H, s, 2-H), 6.38—6.96 (4 H, m, ArH), and 7.04—7.92 (4 H, m, C_6H_4Cl) (Found: C, 63.1; H, 4.1; N, 5.65. $C_{13}H_{10}ClNS$ requires C, 63.03; H, 4.07; N, 5.65%). Recrystallization of this compound was effected from ethanol.

2-(p-*Nitrophenyl*)*benzothiazoline* (**14c**) was similarly prepared, from *p*-nitrobenzaldehyde, as yellow crystals (1.27 g, 98%), m.p. 117—118 °C; $\nu_{max.}$ 3 325, 1 511, and 1 340 cm^{-1}; δ($CDCl_3$) 4.17 (1 H, br, NH), 6.30 (1 H, s, 2-H), 6.51—7.14 (4 H, m, ArH), and 7.44—8.12 (4 H, m, $C_6H_4NO_2$) (Found: C, 60.2; H, 3.9; N, 10.7. $C_{13}H_{10}N_2O_2S$ requires C, 60.45; H, 3.90; N, 10.85%). Recrystallization of this compound was effected from ethanol.

2-(p-*Methoxyphenyl*)*benzothiazoline* (**14a**) was prepared by similar treatment of *o*-amino(thiophenol) with *p*-anisaldehyde at 0 °C, and was obtained as needles (1.16 g, 95%), m.p. 59.5—61 °C; $\nu_{max.}$ 3 348, 1 511, 1 031, and 741 cm^{-1}; δ($CDCl_3$) 3.70 (3 H, s, OMe), 3.75 (1 H, br, NH), 6.20 (1 H, s, 2-H), 6.40—6.95 (4 H, m, ArH), and 7.07—7.93 (4 H, m, C_6H_4OMe) (Found: C, 68.9; H, 5.4; N, 5.7. $C_{14}H_{13}NOS$ requires C, 69.11; H, 5.39; N, 5.76%). Further purification of this compound by recrystallization could not be carried out because it was unstable and gradually decomposed to the corresponding thiazole on being heated.

Reduction of Benzylideneacetone (**3a**) *with the Thiazoline* (**1**) *in the Presence or Absence of a Lewis Acid.*—The reduction of the enone (**3a**) (0.15 g, 1 mmol) was carried out with the thiazoline (**1**) (0.21 g, 1 mmol) in dry methanol (5 ml) at 80 °C for 3 h in the presence or absence of a Lewis acid according to the general procedure described below. The results are summarized in Table 1.

In the reduction employing aluminium chloride (1 mmol), benzylacetone (**5a**) (0.13 g, 87%) and 2-phenylbenzothiazole (**2**) (0.21 g, 98%) were isolated by s.c.c. The thiazole (**2**) had m.p. 111—112 °C (lit.,[22] 113—114 °C); $\nu_{max.}$ 1 496 cm^{-1}; δ($CDCl_3$) 7.13—7.48 (5 H, m, Ph) and 7.65—8.05 (4 H, m, ArH).

General Procedure for the Conjugate Reduction of α,β-Unsaturated Carbonyl Compounds by the Thiazoline (**1**).—A solution of an unsaturated ketone (1.0 mmol) in dry methanol (5 ml), and aluminium chloride (0.16 g, 1.2 mmol), were mixed in a glass tube in an ice–water-bath. After the aluminium chloride had completely dissolved, the thiazoline (**1**) (0.26 g, 1.2 mmol) was added and the mixture was degassed several times under reduced pressure. The tube was sealed *in vacuo* and kept at 80 °C for the appropriate time (Tables 2 and 3). After 0.1M-HCl (5 ml) had been added to the mixture in an ice–water-cooled tube, the aqueous mixture was extracted with chloroform. The extract was washed thoroughly with 0.5M-HCl, and dried with anhydrous Na_2SO_4. The oily residue obtained on evaporation of the solvent was subjected to s.c.c. Elution with hexane–benzene afforded the pure product. The results are given in Tables 2 and 3.

In large-scale syntheses, the reaction could be carried out in a three-necked flask under nitrogen and the same reaction conditions. After work-up as previously described, the product could be isolated by distillation or s.c.c.

Reduction of α,β-Unsaturated Esters (**7**) *and Aldehyde* (**8**) *in the Presence of Aluminium Chloride.*—The reduction of the esters (**7**) and the aldehyde (**8**) (1 mmol) was carried out with the thiazoline (**1**) (0.21 g, 1 mmol) in dry methanol (5 ml) in the presence of aluminium chloride (0.13 g, 1 mmol) at 80 °C for 3 h according to the general procedure. Yields of products were determined by g.l.c. The reduction of methyl cinnamate (**7a**) and ethyl cinnamate (**7b**) yielded only the corresponding saturated esters (**9a**) (18%) and (**9b**) (19%). In the reduction of cinnamaldehyde (**8**), the saturated aldehyde (**10**) could not be detected by g.l.c. analysis at all.

Mixed Reduction of the Enone (**3a**) *with the Ketone* (**11**), *Aldehyde* (**12**), *and Nitrile* (**13**) *by the Thiazoline* (**1**) *in the Presence of Aluminium Chloride.*—A mixture of the enone (**3a**) (0.15 g, 1 mmol) and the ketone (**11**) (0.11 g, 1 mmol) was reduced with the thiazoline (**1**) (0.21 g, 1 mmol) in the presence of aluminium chloride (0.26 g, 2 mmol) according to the general procedure. After the usual work-up, the yields of products were determined by g.l.c. The reduced product (**5a**) was obtained quantitatively, and the ketone (**11**) was recovered in 98% yield.

When the aldehyde (**12**) was used in place of the ketone (**11**), the reduced product (**5a**) was produced in 97% yield, and the aldehyde (**12**) was recovered in 98% yield.

When the nitrile (**13**) was used in place of the ketone (**11**), the reduced product (**5a**) was obtained quantitatively, and the nitrile (**13**) was recovered quantitatively.

Reactivity of p-*Substituted Benzothiazolines* (**14**) *in the Reduction of the Enone* (**3a**) *in the Presence of Aluminium Chloride.*—The enone (**3a**) was reduced with benzothiazolines (**14a—c**) and (**1**) for the appropriate reaction time (Table 4) according to the general procedure. After the usual work-up, the yield of the ketone (**5a**) was determined by g.l.c. The results are given in Table 4.

Reduction of Electron-deficient Olefins (**15**)—(**17**) *with the Thiazoline* (**1**).—(*a*) To a stirred solution of the olefin (**15a**) (0.31 g, 2 mmol) in ethanol (10 ml) at room temperature was added the thiazoline (**1**) (0.51 g, 2.4 mmol). After the mixture had been refluxed for 5 h, the solution was evaporated under reduced pressure and the residue was diluted with methylene dichloride. The organic solution was washed thoroughly and successively with 3M-HCl and saturated aqueous NaCl, and was dried with anhydrous Na_2SO_4. The solid obtained by removal of methylene dichloride was recrystallized from hexane–benzene to give the pure product (**18a**) as needles (0.31 g, 98%), m.p. 90.5—91.5 °C; $\nu_{max.}$ 2 950, 2 200, 1 420, 1 050, 740, and 700 cm^{-1}; δ($CDCl_3$) 3.20 (2 H, d, CH_2), 3.81 [1 H, t, $CH(CN)_2$], and 7.62 (5 H, s, Ph); *m/z* 156 (M^+).

(*b*) To a stirred solution of the olefin (**15b**) or (**15c**) (1 mmol) in butan-1-ol (10 ml) at room temperature was added the thiazoline (**1**) (0.51 g, 2.4 mmol). After the mixture had been refluxed for 24 h, the solvent was evaporated off under reduced pressure. S.c.c. of the oily residue afforded the pure product as an oil: the following compounds were prepared by this method.

(1-Phenylethyl)malononitrile (**18b**) (0.33 g, 97%), b.p. 117—119 °C/6 mmHg; $\nu_{max.}$ 2 900, 2 180, 1 550, 1 460, 760, and 700 cm^{-1}; δ(CCl_4) 1.58 (3 H, d, Me), 3.37 (1 H, m, C*H*Ph), 3.71 [1 H, d, $CH(CN)_2$], and 7.18 (5 H, s, Ph); *m/z* 170 (M^+).

(1-Phenylbutyl)malononitrile (**18c**) (0.37 g, 93%), b.p. 108—110 °C/3 mmHg; $\nu_{max.}$ 2 900, 2 160, 1 460, 1 250, 800, 750, and 700 cm^{-1}; δ(CCl_4) 0.83 (3 H, t, Me), 1.40 (2 H, q, CH_2), 1.91 (2

H, m, CH_2), 2.98 (1 H, q, C*H*Ph), 3.83 [1 H, d, $CH(CN)_2$], and 7.15 (5 H, m, Ph); *m/z* 198 (M^+).

(*c*) To a stirred solution of the olefin (**16**) (0.30 g, 2 mmol) in butan-1-ol (10 ml) at room temperature was added the thiazoline (**1**) (1.02 g, 4.8 mmol). After the mixture had been refluxed for 24 h, the solvent was evaporated off under reduced pressure and the residue was diluted with dry methanol (20 ml). $FeCl_3$ (0.5 g) was added to the methanol solution, which was then stirred for 4 h at 40 °C in order to oxidize completely any unchanged thiazoline (**1**) into the thiazole (**2**). Removal of the solvent under reduced pressure, and s.c.c. of the residue, afforded pure 1-nitro-2-phenylethane (**19**) as an oil (0.24 g, 80%), $\nu_{max.}$ 1 550, 1 380, 740, and 700 cm^{-1}; $\delta(CCl_4)$ 3.11 (2 H, t, CH_2Ph), 4.37 (2 H, t, CH_2NO_2), and 7.09 (5 H, s, Ph); *m/z* 151 (M^+).

(*d*) The olefin (**17**) was reduced by procedure (*a*), except that the scale was halved and butan-1-ol (10 ml) was used in place of ethanol. After a reaction time of 8 h, the solvent was removed by evaporation, and s.c.c. of the residue afforded pure ethyl 2-cyano-3-phenylpropionate (**20**) as oil (0.19 g, 92%), $\nu_{max.}$ 2 240, 1 740, 1 260, 745, and 700 cm^{-1}; $\delta(CCl_4)$ 1.14 (3 H, t, Me), 3.10 (2 H, d, CH_2Ph), 3.48 (1 H, t, 2-H), 4.05 (2 H, q, OCH_2), and 7.10 (5 H, s, Ph); *m/z* 203 (M^+).

Reduction of 2-*Cinnamoylpyridine* (**21**).—(a) *Reduction with the thiazoline* (**1**) *in methanol.* A solution of the enone (**21**) (0.10 g, 0.5 mmol) in dry methanol (2.5 ml), and aluminium chloride (0.08 g, 0.6 mmol), were mixed in a glass tube in an ice–water-bath. After the aluminium chloride had completely dissolved, the thiazoline (**1**) (0.13 g, 0.6 mmol) was added and the mixture was degassed several times under reduced pressure. The tube was sealed *in vacuo* and kept at 80 °C for 3 h. After water (2.5 ml) had been added to the mixture in the tube cooled in an ice–water-bath, the aqueous mixture was extracted with chloroform. The extract was washed thoroughly with water and dried with anhydrous Na_2SO_4. The oily residue obtained by evaporation of the solvent was subjected to s.c.c. to give the pure ketone (**22**) (96 mg, 92%), $\delta(CDCl_3)$ 2.88 (2 H, t, CH_2Ph), 3.40 (2 H, t, CH_2CO), 7.04 (5 H, s, Ph), and 7.17—8.42 (4 H, m, C_5H_4N); *m/z* 211 (M^+).

(b) *Reduction with* 2-*phenyl*[2-^{2}H]*benzothiazoline in acetonitrile.* The enone (**21**) (0.10 g, 0.5 mmol) was similarly reduced with 2-phenyl[2^2-H]benzothiazoline (0.13 g, 0.6 mmol) and aluminium chloride (0.08 g, 0.6 mmol) in acetonitrile (2.5 ml) for 24 h. Chromatographic purification of the crude product gave fully β-monodeuteriated ketone (**23**) (80 mg, 75%), $\delta(CDCl_3)$ 2.88 (1 H, t, CD*H*Ph), 3.40 (2 H, d, CH_2CO), 7.04 (5 H, s, Ph), and 7.17—8.42 (4 H, m, C_5H_4N); *m/z* 212 (M^+).

(c) *Reduction with the thiazoline* (**1**) *in methan*[^{2}H]*ol.* The enone (**21**) (0.10 g, 0.5 mmol) was similarly reduced with the thiazoline (**1**) (0.13 g, 0.6 mmol) in methan[^{2}H]ol (2.5 ml) for 3 h. After D_2O (2.5 ml) has been added to the reaction mixture in an ice–water-cooled tube, the aqueous mixture was extracted with chloroform, and the extract was dried with anhydrous Na_2SO_4. Chromatographic purification of the residue gave the pure non-deuteriated ketone (**22**) (79 mg, 75%), *m/z* 211 (M^+).

Partial Reduction of Ethyl Phenylpropiolate (**28**) *by the Thiazoline* (**1**) *in the Presence or Absence of Lewis Acid.*—A Lewis acid (1 mmol) was added to a stirred solution of the acetylenic ester (**28**) (0.17 g, 1 mmol) in a dry solvent (10 ml) under nitrogen, and the mixture was stirred and refluxed for 5 h. After the mixture had cooled, 0.1M-HCl (5 ml) was added. The aqueous mixture was extracted with chloroform, and the extract was dried with anhydrous Na_2SO_4. The yields of the reduced products were determined by quantitative g.l.c. The reaction in the absence of a Lewis acid was similarly carried out. The completely reduced product (**9b**) could not be detected in these reactions by g.l.c. analysis. The results are given in Table 6. Identification of *Z* and *E* isomers (**29**) and (**7b**) was performed by means of spectroscopic (^{1}H n.m.r. and i.r.) methods: *Z*-isomer (**29**), $\delta(CDCl_3)$ 1.24 (3 H, t, Me), 4.15 (2 H, q, CH_2), 5.46 (1 H, d, *J* 6.4 Hz, =CH), 7.15 (1 H, d, *J* 6.4 Hz, =CH), and 7.50 (5 H, m, Ph); $\nu_{max.}$ 1 710 (C=O) and 1 640 cm^{-1} (C=C); *E*-isomer (**7b**), $\delta(CDCl_3)$ 1.26 (3 H, t, Me), 4.14 (2 H, q, CH_2), 6.27 (1 H, d, *J* 15.8 Hz, =CH), 7.20 (5 H, m, Ph), and 7.53 (1 H, d, *J* 15.8 Hz, =CH); $\nu_{max.}$ 1 710 (C=O) and 1 640 cm^{-1} (C=C).

Reduction of (Z)-1,2-*Dibenzoyl*-1,2-*diphenylethylene* (**30**) *with the Thiazoline* (**1**) *in the Presence of Aluminium Chloride.*—In accordance with the general procedure, compound (**30**) (0.39 g, 1 mmol) was reduced with the thiazoline (**1**) (0.26 g, 1.2 mmol) and aluminium chloride (0.16 g, 1.2 mmol) in methanol at 80 °C for 24 h. Chromatographic isolation of the reduced product from the residue gave only *meso*-1,2-dibenzoyl-1,2-diphenylethane (**31**) (0.14 g, 42%), m.p. 158—162 °C [lit.,[23] 161 °C; racemic mixture (**32**) has m.p. 254—255 °C]; $\delta(CDCl_3)$ 7.06—7.50 (10 H, m, 2 Ph), 7.68 (2 H, d, 2 CH), and 7.78—8.05 (10 H, m, 2 COPh).

References

1 K. Nakamura, A. Ohno, and S. Oka, *Tetrahedron Lett.*, 1983, **24**, 3335; K. Nakamura, M. Fujii, A. Ohno, and S. Oka, *ibid.*, 1984, **25**, 3985; K. Nakamura, M. Fujii, S. Oka, and A. Ohno, *Chem. Lett.*, 1985, 523.

2 C. C. Johnston, J. L. Gardner, C. H. Suelter, and D. E. Metzler, *Biochemistry*, 1963, **2**, 689; C. S. Y. Kim and S. Chaykim, *ibid.*, 1968, **7**, 2339.

3 H. Chikashita, S. Nishida, M. Miyazaki, and K. Itoh, *Synth. Commun.*, 1983, **13**, 1033.

4 H. Chikashita, Y. Morita, and K. Itoh, *Synth. Commun.*, 1985, **15**, 527.

5 H. Chikashita, M. Miyazaki, and K. Itoh, *Synthesis*, 1984, 308.

6 K. Itoh, H. Ishida, and H. Chikashita, *Chem. Lett.*, 1982, 1117.

7 D. Cook, *Can. J. Chem.*, 1963, **41**, 522.

8 R. Futaki, *J. Org. Chem.*, 1958, **23**, 251.

9 R. K. Boeckman, Jr., and R. Michalak, *J. Am. Chem. Soc.*, 1974, **96**, 1623.

10 A. Ohno, T. Shio, H. Yamamoto, and S. Oka, *J. Am. Chem. Soc.*, 1981, **103**, 2045, and references cited therein.

11 P. Yates and P. Eaton, *J. Am. Chem. Soc.*, 1960, **82**, 4436; J. Sauer and J. Kredel, *Tetrahedron Lett.*, 1966, 731; T. Inukai and T. Kojima, *J. Org. Chem.*, 1967, **32**, 869, 872; K. N. Houk and R. W. Strozier, *J. Am. Chem. Soc.*, 1973, **95**, 4094; N. T. Ahn and J. Seyden-Penne, *Tetrahedron*, 1973, **29**, 3259; W. Kreiser, W. Haumesser, and A. F. Thomas, *Helv. Chim. Acta*, 1974, **57**, 164; P. V. Alston and R. M. Ottenbrite, *J. Org. Chem.*, 1975, **40**, 1111; B. B. Snider, *ibid.*, 1974, **39**, 255.

12 N. L. Drake and P. Allen, Jr., *Org. Synth.*, 1956, Coll. Vol. I, 77.

13 E. P. Kohler and H. M. Chadwell, *Org. Synth.*, 1956, Coll. Vol. I, 78.

14 J. D. Billimoria, *J. Chem. Soc.*, 1955, 1126.

15 C. S. Marvel, L. E. Coleman, Jr., and G. P. Scott, *J. Org. Chem.*, 1955, **20**, 1785.

16 C. H. Heathcock, J. E. Ellis, J. E. McMurry, and A. Coppolino, *Tetrahedron Lett.*, 1971, 4995.

17 E. W. Warnhoff, D. G. Martin, and W. S. Johnson, *Org. Synth.*, 1963, Coll. Vol. IV, 162.

18 M. S. Newman, and S. H. Merrill, *J. Am. Chem. Soc.*, 1955, **77**, 5549.

19 R. E. Lutz, C. R. Bauer, R. G. Lutz, and J. S. Gillespie, *J. Org. Chem.*, 1955, **20**, 218.

20 D. Seebach. B. W. Erickson, and G. Singh, *J. Org. Chem.*, 1966, **31**, 4303.

21 S. Tagani, C. Tabuchi, K. Morimoto, and D. Shiho, *Yakugaku Zasshi*, 1974, **94**. 929 (*Chem. Abstr.*, 1975, **82**, 43264).

22 D. W. Hein, R. J. Alheim, and J. J. Leavitt, *J. Am. Chem. Soc.*, 1957, **79**, 427.

23 E. Knoevenagel, *Ber. Dtsch. Chem. Ges.*, 1888, **21**, 1355; M. Pailer and U. Muller, *Monatsh. Chem.*, 1948, **79**, 615 (*Chem. Abstr.*, 1949, **43**, 5020).

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