A Stereocontrolled Approach to Electrophilic Epoxides

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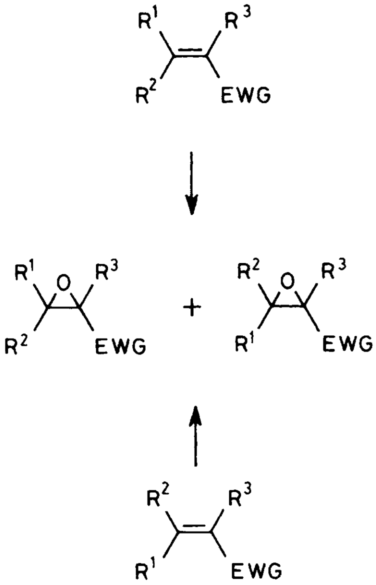
Lithium t-butyl hydroperoxide (easily generated by addition of an alkyl-lithium to anhydrous t-butyl hydroperoxide in THF solution) is a powerful reagent for the epoxidation of electrophilic alkenes at −20 to 0 °C under full stereocontrol.

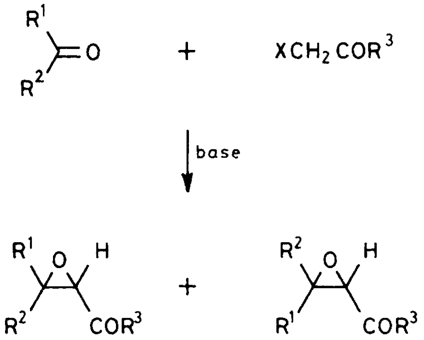
Thus αβ-unsaturated esters, sulphones, sulphoximines, and amides are readily epoxidised with complete regio- and stereo-specificity and with considerable chiroselectivity (20—100%) when appropriate chiral auxiliaries such as menthyl, 8-phenylmenthyl, or a camphor-sulphonamide derivative are used. Asymmetric αβ-unsaturated sulphoximines undergo epoxidation with 100% diastereoselectivity. The only exceptions to stereocontrol noted are heavily substituted maleate esters such as di-t-butyl maleate. The αβ-epoxy amides are shown to be valuable sources of the corresponding epoxy ketones by treatment with an organolithium, allowing a stereo- and chemoselective entry in high yield to these useful intermediates.

Epoxides occupy a key role in synthesis and as such have been the focus of interest in research worldwide. The outstanding efficiency of the Sharpless reaction[1] to generate pure enantiomeric epoxides from allylic alcohols and the varied regiospecific transformation of these building blocks into valuable synthons, represents one of the most important synthetic developments of recent times. However, the equivalent development of stereocontrolled routes to electrophilic epoxides is far from satisfactory. Furthermore, even the Sharpless method has limitations arising from steric problems when substituents occupy particularly the 1-position of the allylic alcohol. With a view to combating both of these gaps in the chemical armoury, we have developed a new, general and powerful stereocontrolled route to electrophilic epoxides,[2] and are investigating the control of the enantiospecificity of the method.

The existing methods to electrophilic epoxides can be summarised under three major groups: (*a*) The Weitz-Scheffer epoxidation which involves the use of alkaline hydrogen peroxide (Scheme 1) is a non-stereospecific reaction, giving the same mixture of epoxides from isomeric alkenes (a process ambiguously referred to by some as 'stereoselective').[3] (*b*) The Darzens reaction involves the condensation of an aldehyde or ketone and an α-halogeno ester or amide under basic catalysis and again tends to yield both possible isomers (Scheme 2).[4] (*c*) Miscellaneous other methods, often very useful but more limited in scope than the last two include, for example, the Payne method,[5] optimised by Sharpless.[6] This method involves tungstate-catalysed epoxidation of α,β-unsaturated acids with aqueous hydrogen peroxide. However, the method lacks regiospecificity and is sensitive to substituents. The enantiomeric epoxides derived from Sharpless epoxidation may be oxidised to various electrophilic oxidation levels without affecting the oxirane function.[7] A number of examples of epoxidation of electrophilic alkenes with various peracids have also been observed, although the method is severely limited. Similarly t-butyl hydroperoxide[8] and hypochlorite solutions[9] have been employed with appropriate additives in certain cases. The unusual fluorine-promoted epoxidation reaction recently described represents one of a few isolated examples of other methods to some electrophilic epoxides.[10]



Scheme 1. Weitz-Scheffer epoxidation. *Reagents:* Alkaline H_2O_2; EWG = COR, NO_2, CN, SO_2R *etc.*



Scheme 2. Darzens reaction

Attempts to induce chiroselectivity into the above methods has also met with only limited success (apart from the oxidation of asymmetric 'Sharpless epoxides'). Thus the Darzens-type

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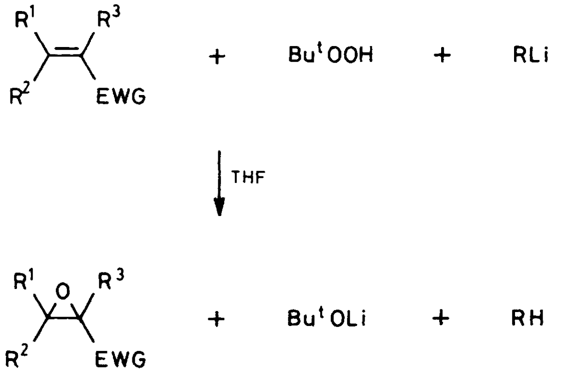
approach using Evans' chiral auxiliary (Scheme 2, R^3 = 4-isopropyloxazolidinyl) and various metal catalysts has been used in a two-step stereoselective generation of two *cis* epoxy esters in both antipodes.[11] Weitz-Scheffer reactions conducted with chiral phase-transfer quaternary ammonium bases[12] or with bovine serum albumin[13] allowed moderate levels of asymmetric induction during the epoxidation of α,β-unsaturated ketones. However, these methods are very limited in scope and efficiency.

The Method.—In this paper we delineate a method for stereocontrolled epoxidation of a variety of electrophilic alkenes. The method is the first regiospecific, stereospecific, general method to effect such epoxidations and is adaptable to be chiroselective or even chirospecific in certain cases. Furthermore, it is cheap, simple and mild in application and allows easy product isolation. The general method is outlined in Scheme 4. A careful study of the epoxidation of methyl cinnamate under various conditions of molar ratios, times, temperatures, and modes of work-up suggested that the best method involved the use of 1.5 equiv. of t-butyl hydroperoxide (TBHP) and 1.1 equiv. of an organolithium. Dependent upon the rate of epoxidation, temperatures of −20 °C to ambient were appropriate. Two major factors proved critical. Methyl esters, in particular, are prone to undergo transesterification with lithium alkoxides, a useful synthetic process.[14] In the present context this proved an annoying side-reaction. Commercial TBHP contains both water (easily removed by azeotroping with benzene) and di-t-butyl peroxide.[8,15] On reaction with an organolithium this mixture could be expected to react as shown in equations (1)—(4). By operating at low



Scheme 4.

$$\mathrm{Bu^tOOH + RLi \longrightarrow Bu^tOOLi + RH} \qquad (1)$$

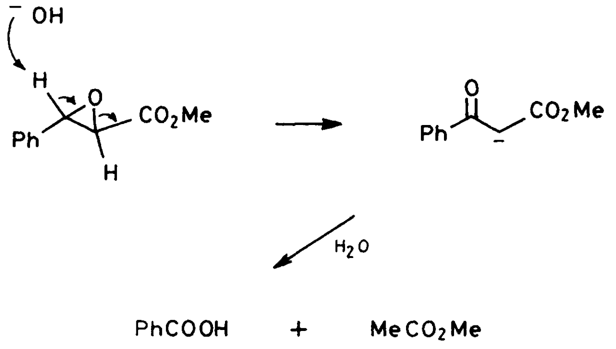
$$\mathrm{Bu^tOOH + RLi \longrightarrow Bu^tOLi + ROH} \qquad (2)$$

$$\mathrm{Bu^tOOBu^t + RLi \longrightarrow Bu^tOLi + Bu^tOR} \qquad (3)$$

$$\mathrm{Bu^tOOBu^t + RLi \longrightarrow Bu^tOOLi + Me_2C{=}CH_2 + RH} \qquad (4)$$

temperature reaction (2) is rendered of minimal significance but it is evident that two alkoxides can be generated in the course of formation of the required lithium t-butyl hydroperoxide as well as that formed during the epoxidation. Consequently, variable amounts of t-butyl epoxy esters contaminate the methyl epoxy ester when an α,β-unsaturated methyl ester is epoxidised and if, say, butyl-lithium is employed as base, small amounts of n-butyl epoxy esters are also noted. In general, it is always best to utilise esters other than methyl in ester epoxidations. The bulkier the ester alcohol component, the less the transesterification. Furthermore, if a methyl ester is used then use of methyl-lithium obviates the problems arising from equation (2).

The mode of work-up is the second key factor. We have found that an aqueous work-up often leads to undesirable ester cleavage and from epoxycinnamates, benzoic acid can be formed, possibly as shown in Scheme 3. The second step is a retro-Claisen reaction while the first rearrangment occurs readily in our experience with *cis*-epoxy carbonyl derivatives and seems feasible as a minor pathway.[16] Albeit these cleavages are minimised by a non-aqueous work-up, best achieved by addition of solid sodium sulphite (to remove remaining peroxides), Celite, and an equal volume of ether. Merely filtration and ether-washing of the solid material produces a good yield of the required product. Such a work-up procedure also obviates problems associated with water-soluble and low molecular weight epoxides.



Scheme 3.

Results and Discussion

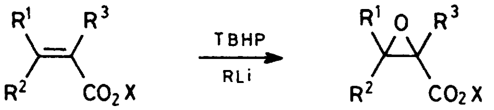
Epoxidation of α,β-Unsaturated Esters.—Epoxidation of a variety of substrate esters is recorded in Table 1, from which a number of important features emerge.

(a) *Generality.* A wide variety of ester types have been transformed into the corresponding epoxy esters including mono- and di-carboxylic, *cis*-, *trans*- and tri-substituted systems. Acrylates react very readily and are best epoxidised at −20 °C but are still reactive even at −70 °C. The reaction is significantly dependent upon steric factors particularly arising from α- and β-substituents and *cis*-enoates react more slowly than their *trans*-isomers (*cf.* expts. 28 and 33). Methyl-lithium was employed for methyl esters but in all other cases butyl-lithium sufficed.

(b) *Regiospecificity.* Electrophilic alkenic sites only were attacked in systems containing both electron-rich and electron-poor double bonds (expts 6 and 7).

(c) *Stereospecificity.* The reactions are totally stereospecific in all but certain sterically crowded maleate esters. Thus di-t-butyl maleate (expt. 41) upon treatment with methyl lithium and TBHP gave solely di-t-butyl fumarate epoxide. Similarly, methyl t-butyl maleate (expt. 40) gave a mixture of *trans*-epoxides (arising from further transesterifications of the initial epoxy ester) with no evidence for the formation of maleate epoxides. The presence of a t-butyl ester group suggests some steric limitations to the stereospecificity of this epoxidation procedure. The stereocontrol derives from a chelate-locking mechanism, whereby the lithium t-butyl hydroperoxide first bonds to the carbonyl oxygen (a feature particularly characteristic of lithium derivatives)[17] (Scheme 5).

Table 1. Epoxidation of α,β-unsaturated esters with t-butyl hydroperoxide (1.5 mol equiv.)–RLi (1.1 mol equiv.) in tetrahydrofuran

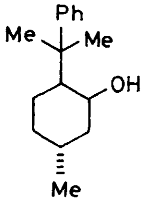


Expt.	Ester,* X =		RLi	Temp. (°C)	Time (h)	Product,* X =		Yield (%)^a	D.e. (%)^b
	Acrylates: R^1 = R^2 = R^3 = H								
1	Me	(**1**)	Bu	20	2	Bu	(**40**)	31^c	
						Bu^t	(**41**)	22^c	
2	Bu	(**2**)	Bu	20	2		(**40**)	59^c	
							(**41**)	16^c	
3	M	(**3**)	Bu	20	1	M	(**42**)	76	19
4				−20	18			67	25
5				−70	6			15	25
6	Cholesteryl	(**4**)	Bu	−20	18	Cholesteryl	(**43**)	80	0
7	Lanosteryl	(**5**)	Bu	−20	3.5	Lanosteryl	(**44**)	51	10
8	8-PM	(**6**)	Bu	−20	18	8-PM	(**45**)	95	40 (70)^d
9	COSA	(**7**)	Bu	−20	18	COSA	(**46**)	95	65
	Crotonates: R^1 = Me, R^2 = R^3 = H								
10	Me	(**8**)	Me	20	2	Me	(**47**)	57^c	
						Bu^t	(**48**)	31^c	
11	Bu	(**9**)	Me	20	16	Bu	(**49**)	61	
12	Bu^i	(**10**)	Me	20	16	Bu^i	(**50**)	50	
13	Bu^i	(**11**)	Bu	−20	20		(**50**)	69	
							(**49**)	15	
							(**48**)	11	
14	M	(**12**)	Bu	−20	70	M	(**51**)	65	35
15	8-PM	(**13**)	Bu	−20	120	8-PM	(**52**)	72	43
16	COSA	(**14**)	Bu	−20	20	COSA	(**53**)	44	26
	Methacrylates: R^1 = R^2 = H, R^3 = Me								
17	M	(**15**)	Bu	−20	70	M	(**54**)	50^e	23
18	8-PM	(**16**)	Bu	−20	120	8-PM	(**55**)	63	74
	Cinnamates: R^1 = Ph, R^2 = R^3 = H								
19	Me	(**17**)	Bu	20	16	Me	(**56**)	93^e	
						Bu^t	(**57**)	5	
20	Et	(**18**)	Bu	20	6	Et	(**58**)	80	
21	Bu^t	(**19**)	Bu	20	48	Bu^t	(**57**)	38	
22	M	(**20**)	Bu	−20	60	M	(**59**)	65^f	40
23	8-PM	(**21**)	Bu	−20	120	8-PM	(**60**)	80^c	55
						Bu	(**61**)	8	
24	COSA	(**22**)	Bu	−20	96	COSA	(**62**)	29	10 (60)^d
	Others: R^1 = R^2 = Me, R^3 = H								
25	M	(**23**)	Bu	20	48	M	(**63**)	51	34
26	8-PM	(**24**)	Bu	20	96	8-PM	(**64**)	63^c	44
27	COSA	(**25**)	Bu	−20	336	COSA	(**65**)	0	
	R^1 = Pr^i, R^2 = R^3 = H								
28	Me	(**26**)	Me	20	72	Me	(**66**)	30	
						Bu^t	(**67**)	8	
						H	(**68**)	42	
29	Bu^t	(**27**)	Bu	20	288	Bu^t	(**67**)	50^e	
30	M	(**28**)	Bu	−20	144	M	(**69**)	38^e	28
						Bu	(**70**)	10	28
31	8-PM	(**29**)	Bu	−20	180	8-PM	(**71**)	38^c	20
	R^1 = R^3 = H, R^2 = Pr^i								
32	Bu^t	(**30**)	Bu	20	240	Bu^t	(**72**)	20^{c,e}	
33	Me	(**31**)	Me	20	144	Me	(**73**)	15	
						H	(**74**)	72^h	
	Fumarates: R^1 = CO$_2$X, R^2 = R^3 = H								
34	Me, Me	(**32**)	Me	20	1	Me, Me	(**75**)	33 (54)^g	
						Me, Bu^t	(**76**)	9	
						H, H	(**77**)	14	

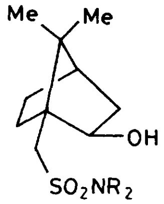
Table 1 (*continued*)

Expt.	Ester,* X =		RLi	Temp. (°C)	Time (h)	Product,* X =		Yield (%)[a]	D.e. (%)[b]
35	Bu^t, Bu^t	**(33)**	Me	20	3	Bu^t, Bu^t	**(78)**	52	
36	Me, M	**(34)**	Bu	20	3	Me, M	**(79)**	35	0
37	M, M	**(35)**	Me	20	18	M, M	**(80)**	63	15
						M, Bu^t	**(81)**	13	15
							(79)	6	14
38	8-PM, 8-PM	**(36)**	Bu	20	18	8-PM, 8-PM	**(82)**	56	50
	Maleates: $R^1 = R^3 = H, R^2 = CO_2X$								
39	Me, Me	**(37)**	Me	20	5	Me, Me	**(83)**	22 (50)[g]	
						Bu^t, Bu^t	**(84)**	3	
						Me, Bu^t	**(85)**	23	
						Me, H	**(86)**	12	
40	Me, Bu^t	**(38)**	Me	20	3		**(75)**	20	
							(78)	6	
							(76)	25	
41	Bu^t, Bu^t	**(39)**	Me	20	3		**(78)**	60	

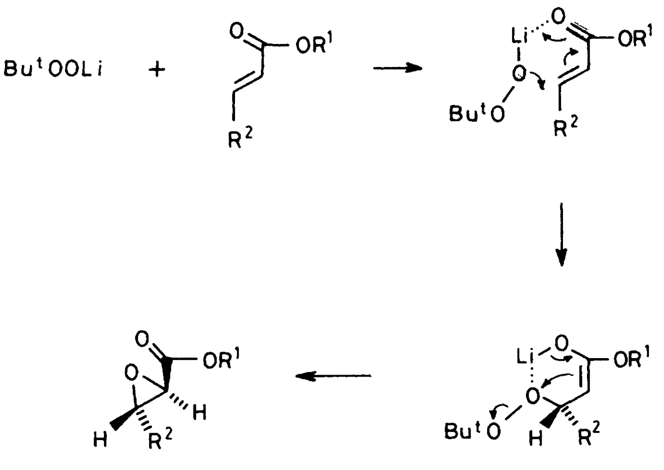
[a] Yields of epoxides based on starting material consumed. [b] Diastereoisomeric excess determined by comparison of intensities of ^{13}C signals of diastereoisomeric mixtures. [c] Inseparable mixtures of epoxides; yields and d.e. of products determined by n.m.r. [d] Diastereoisomeric excess after crystallisation. [e] Starting material recovered. [f] Inseparable mixture of starting material and product; estimate of yield and d.e. from n.m.r. [g] Yield of epoxide after transesterification of mixed epoxy esters with MeOH, toluene-*p*-sulphonic acid, heat, 2 days. [h] Inseparable mixture of *cis-* or *trans*-4-methyl-2,3-epoxypentanoic acids. * M = Menthyl.



A ,8 -PM



B . COSA



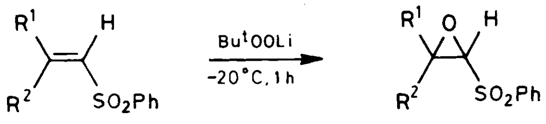
Scheme 5.

It is of interest that the use of potassium t-butyl hydroperoxide in THF as a reagent for the epoxidation of α,β-unsaturated ketones[18] appears to be non-stereospecific in the case of analogous esters. Thus, dimethyl maleate upon epoxidation with potassium t-butyl hydroperoxide gave a mixture of dimethyl maleate epoxide (60%), di-t-butyl maleate epoxide (1%), methyl t-butyl maleate epoxide (5%) together with a small amount of dimethyl fumarate epoxide (5%). By contrast, use of lithium t-butyl hydroperoxide gave a mixture solely comprising maleate epoxides (expt. 39), although the extent of subsequent transesterification was enhanced. The problem of such transesterifications may be overcome by methanolysis of the mixed epoxy esters with methanol and an acid catalyst (expts 34 and 39) which occurs without epoxide cleavage and with stereochemical retention.

(d) *Diastereoselectivity*. An efficient route to enantiomerically pure epoxides of electrophilic alkenes would be of considerable value. Our initial studies involved α,β-unsaturated menthyl esters. Dimenthyl fumarate underwent epoxidation in good yield, also yielding minor amounts of transesterified epoxy esters with poor diastereodifferentiation. Menthyl acrylate gave a diastereoisomeric excess (d.e.) of 25% (expt. 4) when the reaction was carried out at −20 °C. A striking feature is the lack of enhanced selectivity when the reaction is carried out at lower temperatures. All β-alkyl substituents (unlike an α-methyl group) exert a similar beneficial effect upon the chiral discrimination (28—35% d.e., expts. 14 and 30). A β-phenyl group raised the level of diastereoselectivity to 40% d.e. (expt. 22). We next examined 8-phenylmenthol[19] (A) and the camphor-sulphonamide alcohol (B) described by Oppolzer[20] as chiral auxiliaries. The bis-fumarate ester derived from (A) underwent epoxidation at ambient temperature with 55% d.e. showing a significantly higher diastereotopical differentiation compared with the analogous menthyl ester. The corresponding acrylate at −20 °C gave the epoxide with 40% d.e. Upon one crystallisation, the d.e. increased to 70%. Subsequent β-substitution in this series showed slight improvement in stereoselectivity (43—55% d.e., expts. 15, 23 and 26), whereas an α-methyl group raised the d.e. to 74% (expt. 18).

The camphorsulphonamide derived acrylate gave a d.e. of 65% upon epoxidation at −20 °C which did not increase upon recrystallisation. In contrast to the other auxiliaries, the epoxidation of α,β-unsaturated esters derived from (B) having β-substituents (expts. 16 and 24) showed reduced diastereoselectivity. However, this appears to be in line with Sharpless' findings in that asymmetric epoxidation of allylic alcohols often proceeds with low selectivity if a chiral group present in the molecule bears an oxygen atom.[21] Surprisingly, a β,β-dimethyl substituent in this series resulted in no epoxidation even after two weeks (expt. 27).

Epoxidation of α,β-*Unsaturated Sulphones and Sulphoximines*.—A limited number of methods are currently available for the preparation of sulphone epoxides.[22,23] Phenyl β-phenylvinyl sulphones under Weitz-Scheffer conditions undergo epoxidation to give the *trans*-epoxides from both the *cis*-and *trans*-alkenes.[23] Similarly, using potassium t-butylhydroperoxide, *cis*-phenyl β-phenylvinyl sulphone (**87a**) underwent non-stereospecific epoxidation affording both *cis*- and *trans*-epoxides, (**88a**) and (**88b**), in a ratio of 2:3. However, on treatment with lithium t-butyl hydroperoxide (**87a**) gave exclusively the *cis*-epoxide (**88a**) in high yield (Scheme 6).



(**87**) (**88**)

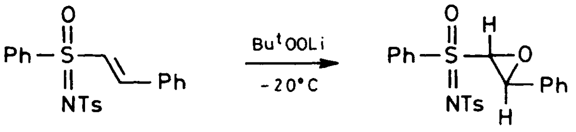
a; R^1 = H, R^2 = Ph a; 90%
b; R^1 = Ph, R^2 = H b; 90%
c; R^1 = R^2 = H c; 90%

Scheme 6.

Similarly, stereospecific epoxidation was observed with the *trans*-isomer (**87b**).

Unsubstituted vinyl sulphones[24] are difficult to oxidise owing to further transformations under the reaction conditions. By using the TBHP/alkyl-lithium system, epoxidation of phenyl vinyl sulphone (**87c**) occurs almost quantitatively at −20 °C to give the potentially valuable oxirane (**88c**).[25]

The corresponding sulphoximine epoxides have not yet been prepared.[26] However, when the readily available chiral (*S*)-(−)-phenyl β-phenylvinyl *N*-(p-tolylsulphonyl)sulphoximine[27] (**89**) was treated with lithium t-butyl hydroperoxide at −20 °C overnight (Scheme 7), an almost quantitative yield of crude epoxide (**90**) was obtained from the reaction mixture. This sulphoximine epoxide appears to be unstable, decomposing slowly in solution at room temperature and upon attempted chromatography. The pure epoxide was isolated in low yield (20%).



(*S*)-(+)-(**89**) (*S*)-(−)-(**90**)

Scheme 7.

Examination of the epoxide (**90**) by ^{13}C n.m.r. indicated that only one enantiomer had been formed, suggesting the epoxidation proceeded with complete enantioselectivity. We are now exploring the vast potential of these systems.

Epoxidation of α,β-*Unsaturated Amides*.—2,3-Epoxy alcohols and their derivatives have proved to be extremely versatile

Table 3. Reaction of epoxy amides with organolithiums (1.5 mol equiv.) in tetrahydrofuran at −78 °C

		R^3Li	Epoxy ketone			
Expt.	Epoxy amide	R^3	R^1	R^3		Yield (%)
61	(**103b**)	Me	Ph	Me	(**111**)	69
62	(**103b**)	Et	Ph	Et	(**112**)	78
63	(**103b**)	Pr	Ph	Pr	(**113**)	70
64	(**103b**)	Bu	Ph	Bu	(**114**)	84
65	(**103b**)	Bu^s	Ph	Bu^s	(**115**)	53
66	(**103b**)	Bu^t	Ph	Bu^t	(**116**)	71
67	(**103b**)	α-C_4H_3O	Ph	α-C_4H_3O	(**117**)	84
68	(**103b**)	Ph	Ph	Ph	(**118**)	80
69	(**92b**)	Bu	H	Bu	(**119**)	47
70	(**92b**)	Ph	H	Ph	(**120**)	39
71	(**97b**)	Bu	Me	Bu	(**121**)	58

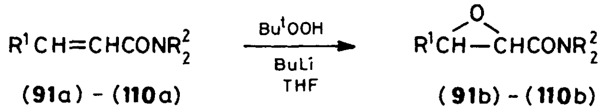
Table 2. Epoxidation of α,β-unsaturated amides with t-butyl hydroperoxide (1.5 mol equiv.)–butyl lithium (1.1 mol equiv.) in tetrahydrofuran at ambient temperature

Expt.	Amide		Time (h)	Product	Yield (%)
42	CH_2=CHCONEt_2	(**91a**)	1	(**91b**)	40
43	CH_2=CHCONPh_2	(**92a**)	1	(**92b**)	34
			2^a		78
44	CH_2=CHCON(cyclohexyl)$_2$	(**93a**)	5^a	(**93b**)	76
45	CH_2=CHCONC_4H_8	(**94a**)	0.25	(**94b**)	53
46	*t*-CH_3CH=CHCONEt_2	(**95a**)	2	(**95b**)	48
47	*t*-CH_3CH=CHCONPh_2	(**96a**)	1.5	(**96b**)	65
48	*t*-CH_3CH=CHCONC_4H_8	(**97a**)	1	(**97b**)	83
49	*c*-CH_3CH=CHCONEt_2	(**98a**)	6	(**98b**)	65
50	*t*-PhCH=CHCONMe_2	(**99a**)	24	(**99b**)	83
51	*t*-PhCH=CHCONEt_2	(**100a**)	120	(**100b**)	71
52	*t*-PhCH=CHCONPr^i_2	(**101a**)	72	(**101b**)	88
53	*t*-PhCH=CHCONPh_2	(**102a**)	2	(**102b**)	71
54	*t*-PhCH=CHCONC_4H_8	(**103a**)	1.5	(**103b**)	71
55	*t*-PhCH=CHCON(CH_2Ph)$_2$	(**104a**)	4	(**104b**)	91
56	*t*-PhCH=CHCONH_2	(**105a**)	24	(**105b**)	0
57	*t*-PhCH=CHCONHMe	(**106a**)	288	(**106b**)	31
58	*t*-PhCH=CHCONHBu^t	(**107a**)	120	(**107b**)	38
59	Me_2C=CHCONC_4H_8	(**108a**)	168	(**108b**)	58
60	*t*-Pr^iCH=CHCONC_4H_8	(**109a**)	40	(**109b**)	68
61	*c*-Pr^iCH=CHCONC_4H_8	(**110a**)	284	(**110b**)	25

[a] Reaction conducted at −20 °C.

intermediates in that a number of procedures are available which allow for selective attack at each of the three functionalised carbon atoms.[28] At the carboxylic acid oxidation level, there is a change in selectivity on going from epoxy acids (C-2 attack)[29] to epoxy amides (C-3 attack).[21] Furthermore, 2,3-epoxy amides have shown extended selectivities. In sharp contrast to ring opening of epoxy amides at C-3 with nitrogen nucleophiles, sulphur nucleophiles show a preference for attack at C-2.[30] Thus, 2,3-epoxy amides have been shown to undergo highly specific epoxide ring-openings leading to valuable synthetic intermediates.

α,β-Unsaturated t-amides undergo epoxidation with lithium t-butyl hydroperoxide with full regio- and stereo-control with no significant side-reactions (Scheme 8 and Table 2). The epoxidation is very effective for tertiary amides but poor for seconday amides (expts. 57 and 58) and ineffective for primary amides (expt. 56). Apart from the special case of acrylamides, pyrrolidides are generally the most efficient amides to epoxidise (*e.g.*, *cf.* expts. 50—53 with expt. 54). With acrylamides larger amine substituents (expts. 43 and 44) favour easy isolation and purification of otherwise problematic products. Unlike the epoxidation of the analogous esters, where some trans-esterification is observed, amides are, in general, stable to the reaction conditions. However, in line with literature observations,[31] a little diphenylamine is isolated from diphenylamides. As is the case with the corresponding esters, *cis*-isomers undergo epoxidation more slowly than the *trans*-isomers, and the rate of reaction is also sensitive to the size of β-substituents.



Scheme 8.

Table 4. Physical data for some previously unreported α,β-unsaturated esters

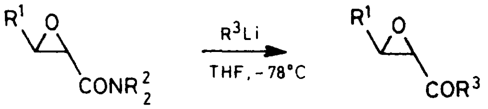
					Elemental analysis (%)	
					Found	(Required)
Ester	Method	M.p. (°C)	$\nu_{max.}$/cm^{-1}	^{1}H N.m.r. (δ_H)	C	H
(**4**)	a[14]	122.5—124.5 (hexane)	1 725, 1 650	0.75—2.50 (43 H, m), 4.70 (1 H, m), 5.40 (1 H, m), 5.80 (1 H, m), 6.30 (2 H, m)	81.5 (81.6)	11.38 (11.18)
(**5**)	a	105—107 (hexane)	1 725, 1 650	0.70—2.20 (47 H, m), 4.65 (1 H, m), 5.15 (1 H, m), 5.80 (1 H, m), 6.30 (2 H, m)		
(**13**)	a	Oil	1 710, 1 660	0.85—2.10 (17 H, m), 1.75 (3 H, dd, *J* 7 and 1.5 Hz), 4.85 (1 H, dt, *J* 11 and 4.5 Hz), 5.35 (1 H, dd, *J* 16 and 1.5 Hz), 6.50 (1 H, dq, *J* 16 and 7 Hz), 7.30 (5 H, br s)		
(**16**)	a	Oil	1 720, 1 645	0.80—2.30 (17 H, m), 1.70 (3 H, s), 4.95 (1 H, dt, *J* 11.5 and 5 Hz), 5.30 (1 H, br s), 5.70 (1 H, br s), 7.30 (5 H, br s)		
(**21**)	a	Oil	1 700, 1 650	0.80—2.30 (17 H, m), 4.95 (1 H, dt, *J* 11 and 5 Hz), 5.80 (1 H, d, *J* 15.5 Hz), 7.10—7.45 (11 H, m)		
(**22**)	b[33]	128—130 (hexane)	1 720, 1 660, 1 340, 1 180	0.80—2.30 (33 H, m), 2.80 (1 H, d, *J* 2.5 Hz), 3.30 (2 H, m), 3.40 (1 H, d, *J* 12.5 Hz), 5.25 (1 H, m), 6.50 (1 H, d, *J* 15 Hz), 7.40 (5 H, m), 7.75 (1 H, d, *J* 15 Hz)	70.2 (70.5)	8.67 (8.59)
(**24**)	a	Oil	1 705, 1 660	0.90—2.30 (17 H, m), 1.75 (3 H, s), 2.10 (3 H, s), 4.85 (1 H, dt, *J* 11 and 4.5 Hz), 5.10 (1 H, br s), 7.30 (5 H, br s)		
(**25**)	b	180—182 (hexane)	1 725, 1 665, 1 340, 1 170	0.80—2.15 (33 H, m), 1.90 (3 H, s), 2.30 (3 H, s), 2.70 (1 H, d, *J* 12.5 Hz), 3.30 (2 H, m), 3.40 (1 H, d, *J* 12.5 Hz), 5.00 (1 H, m), 5.70 (1 H, br s)	67.5 (67.6)	9.42 (9.46)
(**28**)	a	Oil	1 715, 1 650	0.75—2.30 (24 H, m), 2.50 (1 H, m), 4.80 (1 H, dt, *J* 11 and 4.5 Hz), 5.85 (1 H, d, *J* 15 Hz), 7.05 (1 H, dd, *J* 15 and 7 Hz)		
(**29**)	c[34]	Oil	1 720, 1 660	0.80—2.30 (19 H, m), 2.60 (1 H, m), 4.90 (1 H, dt, *J* 11 and 4.5 Hz), 5.20 (1 H, d, *J* 15 Hz), 6.65 (1 H, dd, *J* 15 and 7 Hz), 7.30 (5 H, br s)		
(**36**)	a	Oil	1 710, 1 640	0.85—2.20 (34 H, m), 4.85 (2 H, dt, *J* 11 and 4.5 Hz), 5.75 (2 H, s), 7.25 (10 H, br s)		
(**38**)	a	Oil	1 700, 1 640	1.50 (9 H, s), 3.80 (3 H, s), 6.80 (2 H, s)	58.0 (58.1)	7.34 (7.78)
(**39**)	a	Oil	1 700, 1 645	1.52 (18 H, s), 6.70 (2 H, s)	62.7 (63.1)	8.59 (8.83)

Table 5. Physical data for α,β-unsaturated amides previously unreported

Amide	M.p. (°C)	$\nu_{max.}$/cm^{-1}	^{1}H N.m.r. (δ_H)	Elemental analysis (%)	
				Found	(Required)
(93a)	79—80 (hexane)	1 640, 1 600	1.20—2.00 (20 H, m), 3.45 (2 H, m), 5.55 (1 H, dd, *J* 4.2 and 1 Hz), 6.15 (1 H, dd, *J* 7 and 1 Hz), 6.58 (1 H, dd, *J* 7 and 4.2 Hz)		
(94a)	Oil	1 645, 1 600	1.80—2.20 (4 H, m), 3.45—3.70 (4 H, m), 5.70 (1 H, dd, *J* 7.5 and 4 Hz), 6.45 (2 H, m)		
(97a)	Oil	1 640, 1 600	1.85—2.05 (7 H, m), 3.45—3.65 (4 H, m), 6.15 (1 H, dd, *J* 15 and 1 Hz), 6.90 (1 H, dq, *J* 15 and 7 Hz)		
(98a)	Oil	1 640, 1 600	1.10 (6 H, m), 1.95 (3 H, dd, *J* 7 and 1 Hz), 3.35 (4 H, m), 6.00 (2 H, m)		
(103a)	101.5—102 (hexane)	1 650, 1 600	1.80—2.05 (4 H, m), 3.50—3.70 (4 H, m), 6.75 (1 H, d, *J* 15 Hz), 7.25—7.60 (5 H, m), 7.75 (1 H, d, *J* 15 Hz)	77.7 (77.6)	7.74 (7.51)
(108a)	Oil	1 655, 1 620	1.75—2.15 (10 H, m), 3.35—3.60 (4 H, m), 5.80 (1 H, br s)		
(109a)	Oil	1 655, 1 615	1.03 (3 H, s), 1.09 (3 H, s), 1.80—2.05 (4 H, m), 3.45—3.70 (4 H, m), 6.05 (1 H, dd, *J* 15 and 1 Hz), 6.95 (1 H, dd, *J* 15 and 6 Hz)		
(110a)*	Oil	1 645, 1 615	0.95 (3 H, s), 1.05 (3 H, s), 1.80—2.10 (4 H, m), 3.30—3.60 (5 H, m), 5.75 (2 H, m)		

* *cis*-Amide contains 11% *trans*-isomer (by n.m.r.). See ref. 36

Conversion of Epoxy Amides to Epoxy Ketones with Organolithiums.—Subsequent treatment of α,β-epoxy amides with an organolithium at −78 °C in tetrahydrofuran solution allows rapid and efficient access to α,β-epoxy ketones with complete chemo- and stereo-specificity and in high yield (Scheme 9).* Some examples are shown in Table 3. The generality and specificity is again evident. With acrylamides we found it more convenient to utilise the easily made diphenylamide rather than the substituted pyrrolidine.



(111) - (121)

Scheme 9.

Experimental

M.p.s were recorded on a Reichert Kofler hot-stage apparatus and are uncorrected. I.r. spectra were obtained on a Perkin-Elmer 257 or 883 spectrophotometer as liquid films or chloroform solutions. ^{1}H N.m.r. spectra were recorded on a Varian EM-390 operating at 90 MHz. The n.m.r. data refer to deuteriochloroform solutions referenced to tetramethylsilane as internal standard. ^{13}C N.m.r. spectra were recorded on a Bruker WM500 spectrometer (125 MHz) for deuteriochloroform solutions. Mass spectra were obtained on a Varian MAT 212 instrument. Chromatography utilised silica throughout; t.l.c. plates were Merck Silica Gel 60 F254, while for column chromatography Merck Silica Gel 60 (70—230 mesh) was used. Flash chromatography was performed with Merck Silica Gel 60 (230—400 mm) as described by Still.[32] Petroleum refers to light petroleum, b.p. 60—80 °C, whilst ether refers to diethyl ether. Tetrahydrofuran was freshly distilled from sodium/benzophenone prior to use. Anhydrous solutions of t-butyl hydroperoxide were prepared by azeotroping the commercially available 70% aqueous t-butyl hydroperoxide solution (obtained from Fluka) with benzene according to the method described in the literature.[15] All other commercial chemicals and reagents were used as received. Both 8-phenylmenthol[19] and Oppolzer's camphorsulphonamide[20] were prepared by methods described in the literature. α,β-Unsaturated esters were either commercially available or prepared by literature procedures. Esters which had not previously been described were prepared by the usual methods of esterification,[14,33,34] unless otherwise stated. The physical data for these compounds are given in Table 4. Similarly, α,β-unsaturated amides were prepared by treatment of the corresponding acid chlorides with the requisite amines. The amides obtained in this matter gave analytical data in agreement with that described in the literature. The α,β-unsaturated amides which had not previously been prepared are described in Table 5.

All epoxidations were conducted in oven-dried (140 °C) or flame-dried glassware, under an inert atmosphere (argon or nitrogen). The reactions are conveniently followed by t.l.c., and the epoxides were visualised by the spray reagent described by Hammock *et al.*[35] comprised of 4-(*p*-nitrobenzyl)pyridine and tetraethylene pentamine.

t-*Butyl* cis-4-*Methylpent*-2-*enoate* **(30)**.—A solution of potassium t-butoxide in t-butyl alcohol (1 M solution; 55.5 ml

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* It is worth noting that Grignard reagents react in a non-chemoselective manner. Thus, phenylmagnesium bromide reacts with *N*-epoxycinnamoylpyrrolidine **(103b)** to give both the epoxy ketone **(118)** (47%) and the product of β-attack of the epoxide ring, 1-(2-hydroxy-3,3-diphenylpropionyl)pyrrolidine (33%).

Table 6. Physical data for epoxy esters (**42**)—(**86**)

Epoxy ester	M.p. (°C) (lit. m.p.)	$\nu_{max.}$/cm^{-1}	^{1}H N.m.r. (δ_H)	Elemental analysis (%)	
				(Found)	(Required)
(**42**)	Oil	1 745, 1 250, 910, 825	0.85—2.15 (18 H, m), 2.95 (2 H, m), 3.45 (1 H, dd, *J* 4.5 and 3 Hz), 4.80 (1 H, dt, *J* 10 and 5 Hz)		
(**43**)	126—127 (MeOH)	1 735, 1 255, 910, 800	0.80—2.20 (41 H, m), 2.50 (2 H, m), 3.00 (2 H, m), 3.50 (1 H, dd, *J* 4.5 and 3.5 Hz), 4.80 (1 H, m), 5.45 (1 H, m)	79.0 (79.2)	10.94 (10.20)
(**44**)	111—113 (hexane)	1 745, 1 250, 910, 830	0.75—2.15 (47 H, m), 2.95 (2 H, m), 3.45 (1 H, dd, *J* 4.5 and 3 Hz), 4.65 (1 H, m), 5.15 (1 H, m)	79.5 (79.8)	10.57 (10.55)
(**45**)	86—88 (pentane)	1 745, 1 250, 910, 820	0.85—2.25 (16 H, m), 2.50 (1 H, br s), 2.65 (2 H, m), 3.75 (1 H, m), 4.90 (1 H, dt, *J* 10 and 4 Hz), 7.25 (5 H, m)	75.8 (75.5)	8.85 (8.67)
(**46**)	174.5—176 (EtOAc–hexane)	1 735, 1 330, 1 255, 1 165, 895, 790	0.90 (3 H, s), 1.05 (3 H, s), 1.20—2.15 (27 H, m), 2.75 (1 H, d, *J* 12.5 Hz), 3.00 (2 H, m), 3.20 (1 H, d, *J* 12.5 Hz), 3.25 (3 H, m), 5.05 (1 H, m)	64.0 (64.2)	8.82 (8.84)
(**47**)	150 (150) [a]				
(**48**)	Oil	1 745, 1 250, 865, 790	1.40 (3 H, d, *J* 6 Hz), 1.15 (9 H, s), 3.05 (2 H, m)	61.2 (60.7)	8.70 (8.92)
(**49**)	Oil	1 720, 1 245, 860	0.98 (3 H, t), 1.50 (7 H, m), 3.23 (2 H, m), 4.20 (2 H, t)	60.3 (60.7)	9.00 (8.92)
(**50**)	Oil	1 720, 1 245, 860	1.00 (6 H, d, *J* 6 Hz), 1.40 (3 H, d, *J* 4.5 Hz), 1.90 (1 H, m), 3.20 (2 H, m), 3.95 (2 H, d, *J* 7 Hz)	60.3 (60.7)	9.19 (8.92)
(**51**)	Oil	1 745, 1 250, 905, 790	0.70—2.15 (18 H, m), 1.35 (3 H, d, *J* 5 Hz), 3.15 (2 H, m), 4.80 (1 H, dt, *J* 10 and 4.5 Hz)		
(**52**)	Oil	1 740, 1 250, 905, 785	0.80—2.30 (17 H, m), 1.30 (3 H, d, *J* 6 Hz), 2.45 (1 H, d, *J* 1.5 Hz), 3.05 (1 H, m), 4.85 (1 H, dt, *J* 10 and 4 Hz), 7.25 (5 H, m)		
(**53**)	Oil	1 730, 1 260, 895, 820	0.90 (3 H, s), 1.05 (3 H, s), 1.15—2.30 (30 H, m), 2.70 (1 H, d, *J* 12.5 Hz), 3.10—3.40 (5 H, m), 5.00 (1 H, m)		
(**54**)	Oil	1 730, 875, 760	0.75—2.15 (21 H, m), 2.75 (1 H, d, *J* 6 Hz), 3.15 (1 H, d, *J* 6 Hz), 4.80 (1 H, dt, *J* 10 and 4.5 Hz)		
(**55**)	Oil	1 735, 905 760	0.80—2.20 (20 H, m), 2.80 (1 H, d, *J* 6 Hz), 3.15 (1 H, d, *J* 6 Hz), 4.90 (1 H, dt, *J* 10 and 4.5 Hz), 7.25 (5 H, br s)		
(**58**)	105/1 mmHg (96/0.5 mmHg) [b]				
(**61**)	Oil	1 730, 1 250, 880, 780	0.95 (3 H, m), 1.30—1.85 (4 H, m), 3.50 (1 H, d, *J* 1.5 Hz), 4.15 (1 H, d, *J* 1.5 Hz), 4.20 (2 H, t, *J* 6.5 Hz), 7.35 (5 H, br s)		
(**62**)	165.5—167 (hexane)	1 735, 1 330, 1 250, 1 160, 900, 790	0.85 (3 H, s), 0.95—2.30 (27 H, m), 1.10 (3 H, s), 2.75 (1 H, d, *J* 13 Hz), 3.30 (3 H, m), 3.55 (1 H, d, *J* 1.5 Hz), 4.15 (1 H, d, *J* 1.5 Hz), 5.10 (1 H, m), 7.40 (5 H, br s)	68.6 (68.5)	8.50 (8.34)
(**63**)	Oil	1 745, 1 255, 910, 820	0.70—2.15 (24 H, m), 3.30 (1 H, br s), 4.80 (1 H, dt, *J* 10 and 5 Hz)		
(**64**)	Oil	1 740, 1 250, 900, 810	0.85—2.15 (17 H, m), 1.20 (3 H, s), 1.30 (3 H, s), 2.90 (1 H, br s), 4.90 (1 H, dt, *J* 10.5 and 5 Hz), 7.30 (5 H, br s)		
(**66**)	Oil	1 740, 1 245, 895, 815	1.00 (6 H, dd, *J* 6 and 4 Hz), 1.68 (1 H, m), 3.00 (1 H, dd, *J* 7.5 and 1.5 Hz), 3.28 (1 H, d, *J* 1.5 Hz), 3.78 (3 H, s)	57.9 (58.3)	8.58 (8.39)
(**67**)	Oil	1 740, 1 250, 900, 820	1.00 (6 H, dd, *J* 6 and 3 Hz), 1.48 (9 H, s), 1.49 (1 H, m), 2.95 (1 H, dd, *J* 6 and 1.5 Hz), 3.15 (1 H, d, *J* 1.5 Hz)	64.4 (64.4)	10.00 (9.74)

Table 6 (*continued*)

Epoxy ester	M.p. (°C) (lit. m.p.)	$\nu_{max.}$/cm^{-1}	^{1}H N.m.r. (δ_H)	Elemental analysis (%)	
				(Found)	(Required)
(**68**)	Oil	1 720, 1 240, 890, 815	1.00 (6 H, dd, *J* 6 and 3 Hz), 1.70 (1 H, m), 3.50 (1 H, dd, *J* 6 and 1.5 Hz), 3.75 (1 H, d, *J* 1.5 Hz), 7.15 (1 H, s)	55.6 (55.4)	7.98 (7.74)
(**69**)	Oil	1 735, 900, 820	0.70—2.10 (25 H, m), 2.95 (1 H, m), 3.25 (1 H, d, *J* 1.5 Hz), 4.80 (1 H, dt, *J* 10 and 4.5 Hz)		
(**70**)	Oil	1 730, 1 250, 885, 790	0.90—1.85 (14 H, m), 3.00 (1 H, m), 3.30 (1 H, d, *J* 1.5 Hz), 4.20 (2 H, t, *J* 6 Hz)		
(**73**)	Oil	1 750, 1 210, 910, 800	1.02 (6 H, dd, *J* 21 and 6 Hz), 1.60 (1 H, m), 2.86 (1 H, dd, *J* 10.5 and 4.5 Hz), 3.57 (1 H, d, *J* 4.5 Hz), 3.80 (3 H, s)	58.7 (58.3)	8.60 (8.39)
(**75**)	74.5 (75—76)[c]				
(**76**)	Oil	1 735, 1 240, 890, 830	1.50 (9 H, s), 3.55 (1 H, d, *J* 1.5 Hz), 3.60 (1 H, d, *J* 1.5 Hz), 3.78 (3 H, s)	53.5 (53.5)	6.99 (6.98)
(**77**)	208 (207—209)[d]				
(**78**)	53.5—55.5	1 730, 1 240, 900, 830	1.55 (18 H, s), 3.46 (2 H, s)	58.9 (59.0)	8.61 (8.25)
(**79**)	Oil	1 740, 1 260, 920, 850	0.75—2.15 (18 H, m), 3.65 (2 H, s), 3.80 (3 H, s), 4.85 (1 H, dt, *J* 11 and 5 Hz)		
(**80**)	Oil	1 745, 1 250, 900, 785	0.70—2.15 (36 H, m), 3.60 (2 H, s), 4.80 (2 H, dt, *J* 10 and 4.5 Hz)		
(**81**)	Oil	1 735, 1 250, 900, 820	0.75—2.20 (18 H, m), 1.50 (9 H, s), 3.55 (2 H, m), 4.80 (1 H, dt, *J* 10 and 4.5 Hz)		
(**82**)	Oil	1 740, 1 260, 910, 810	0.80—2.30 (34 H, m), 3.05 (2 H, s), 4.85 (2 H, dt, *J* 11 and 5 Hz), 7.30 (10 H, br s)		
(**83**)	80/1 mmHg (240—244/760 mmHg)[c]				
(**84**)	85.5	1 740, 1 240, 900, 800	1.50 (18 H, s), 3.57 (2 H, s)	59.3 (59.0)	8.47 (8.25)
(**85**)	Oil	1 735, 1 240, 920, 800	1.45 (9 H, s), 3.70 (2 H, dd, *J* 10.5 and 4.5 Hz), 3.90 (3 H, s)		
(**86**)	Oil	3 500, 1 700, 1 240, 890	3.60 (2 H, dd, *J* 13.5 and 4.5 Hz), 3.80 (3 H, s), 8.70 (1 H, br s)	40.7 (41.1)	4.50 (4.10)

[a] R. K. Hill, S. Yan, and S. M. Arfin, *J. Am. Chem. Soc.*, 1973, **95**, 7859. [b] H. O. House, J. W. Blaker, and D. A. Madden, *J. Am. Chem. Soc.*, 1958, **80**, 6386. [c] O. Gawron, A. J. Glaid, A. Lamonte, and S. Gary, *J. Am. Chem. Soc.*, 1958, **80**, 5856. [d] G. B. Payne, *J. Org. Chem.*, 1959, **24**, 2048.

0.056 mol) was added to *cis*-4-methylpent-2-enoyl chloride[36] (6.54 g, 0.05 mol) at 0 °C and the resulting mixture was stirred at room temperature for 2 days. The resulting solid was filtered off and the filtrate concentrated under reduced pressure. The residual oil was distilled using a Kügelrohr apparatus to give the title compound (**30**) as a colourless oil (3.00 g, 35%), b.p. 60 °C/mmHg (Found: C, 69.9; H, 10.4. $C_{10}H_{18}O_2$ requires C, 70.5; H, 10.7%); $\nu_{max.}$ 1 715 (CO) and 1 638 (C=C) cm^{-1}; δ_H 1.05 (6 H, d, *J* 6 Hz), 1.50 (9 H, s), 3.55 (1 H, m), 5.55 (1 H, d, *J* 11 Hz), and 5.90 (1 H, dd, *J* 11 Hz and 9 Hz).

Epoxidation of α,β-*Unsaturated Esters and Amides*.—The following procedure, described for methyl cinnamate, is representative of the epoxidation of α,β-unsaturated esters and amides. An anhydrous solution of t-butyl hydroperoxide in benzene (4.85 M solution; 3.80 ml, 18.5 mmol, 1.5 equiv.) was added to freshly distilled THF (30 ml) at −78 °C under an atmosphere of argon. This was followed by the addition of a solution of butyl-lithium in hexane (1.6 M solution; 8.20 ml, 13.6 mmol, 1.1 equiv.). The resulting solution was stirred at −78 °C for 5 min, after which a solution of methyl cinnamate (2.00 g, 12.4 mmol) in dry THF (10 ml) was added. The reaction mixture was then stirred at room temperature for 16 h. After completion of the reaction (monitored by t.l.c.), solid sodium sulphite (*ca.* 1 g) was added and the mixture was stirred for 15 min. The mixture was then diluted with ether (50 ml), filtered through Celite, and the filtrate concentrated under reduced pressure. Flash chromatography (hexane–ethyl acetate, 4:1, as eluant) of the residual oil afforded *trans*-methyl 3-phenyl-2,3-epoxypropanoate (**56**) as a colourless oil (2.03 g, 93%), b.p. 100 °C/mmHg (lit.,[37] b.p. 121—122 °C/4 mmHg), followed by *t-butyl* trans-3-*phenyl*-2,3-*epoxypropanoate* (**57**) as a white solid (0.13 g, 5%), m.p. 58.5 °C (from hexane) (Found: C, 70.3; H, 7.4. $C_{13}H_{16}O_3$ requires C, 70.9; H, 7.32%); $\nu_{max.}$ 1 740 (CO), 1 240, 1 154, 894, and 733 cm^{-1}; δ_H 1.52 (9 H, s), 3.40 (1 H, d, *J* 1.5 Hz), 4.00 (1 H, d, *J* 1.5 Hz), and 7.32 (5 H, s).

The physical data for a number of epoxides prepared by this general method are given in Tables 6 and 7.

cis-*Phenyl* β-*Styryl Sulphone* (**87a**).—This compound was prepared by the method described by Oswald *et al.*[38] to give the title compound (**87a**), m.p. 64—68 °C (lit.,[38] m.p. 61—62 °C).

Table 7. Physical data for some 2,3-epoxy amides (**91b**)—(**110b**)

Epoxy amide	M.p. (°C) (lit. m.p.)	$\nu_{max.}$/cm^{-1}	^{1}H N.m.r. (δ_H)	Elemental analysis (%)	
				(Found)	(Required)
(**91b**)	Oil	1 650, 1 220, 910, 820	1.10 (3 H, t, *J* 7 Hz), 1.25 (3 H, t, *J* 7 Hz), 3.00 (2 H, m), 3.50 (5 H, m)		
(**92b**)	Oil	1 670, 1 250, 895, 810	2.75 (1 H, dd, *J* 6.5 and 4 Hz), 3.05 (1 H, dd, *J* 6.5 and 2.5 Hz), 3.25 (1 H, dd, *J* 4 and 2.5 Hz), 7.30 (10 H, br s)		
(**93b**)	Oil	1 645, 1 240, 895, 810	1.15—2.00 (20 H, m), 2.90 (2 H, m), 3.60 (3 H, m)		
(**94b**)	Oil	1 650, 1 240, 900, 810	1.95 (4 H, m), 2.95 (2 H, m), 3.55 (5 H, m)	M^+, 141.0789 $C_7H_{11}NO_2$ requires 141.0790	
(**95b**)	Oil	1 650, 1 265, 910, 815	1.20 (6 H, m), 1.40 (3 H, d, *J* 5 Hz), 3.15 (2 H, m), 3.55 (4 H, m)		
(**96b**)	91.5—92 (EtOAc–hexane)	1 675, 1 245, 885, 800	1.10 (3 H, d, *J* 5 Hz), 2.90 (1 H, d, *J* 1.5 Hz), 3.20 (1 H, dd, *J* 5 and 1.5 Hz), 7.25 (10 H, br s)	75.7 (75.8)	5.88 (5.97)
(**97b**)	Oil	1 650, 1 250, 900, 810	1.40 (3 H, d, *J* 5 Hz), 1.85 (4 H, m), 3.25 (1 H, d, *J* 1.5 Hz), 3.60 (5 H, m)		
(**98b**)*	Oil	1 645, 1 265, 905, 815	1.20 (9 H, m), 3.40 (6 H, m)	M^+, 141.1130 $C_8H_{15}NO_2$ requires 141.1154	
(**99b**)	160 °C/1 mmHg (180 °C/3.5 mmHg)[a]				
(**100b**)	87—88 (88.0—88.4)[b]				
(**101b**)	65—66 (hexane)	1 645, 1 240, 905, 790	1.45 (14 H, m), 3.55 (1 H, d, *J* 2 Hz), 4.10 (1 H, d, *J* 2 Hz), 7.35 (5 H, s)	72.7 (72.8)	8.54 (8.56)
(**102b**)	110.5—111.5 (111—112)[c]				
(**103b**)	82—84 (EtOAc–hexane)	1 650, 1 240, 895, 815	1.90 (4 H, m), 3.50 (1 H, d, *J* 1.8 Hz), 3.60 (4 H, m), 4.15 (1 H, d, *J* 1.8 Hz), 7.30 (5 H, s)	72.2 (71.9)	7.08 (6.96)
(**104b**)	122—122.5 (EtOH)	1 650, 1 220, 885	3.65 (1 H, d, *J* 2 Hz), 4.15 (1 H, d, *J* 2 Hz), 4.60 (2 H, d, *J* 10 Hz), 7.25 (15 H, br s)	80.2 (80.4)	6.22 (6.17)
(**106b**)	123—125 (EtOH)	3 430, 1 680, 1 240, 905, 815	2.60 (1 H, br s, exchanges with D_2O), 3.00 and 3.10 (3 H, rotameric N-Me), 3.55 (1 H, d, *J* 1.5 Hz), 4.05 (1 H, d, *J* 1.5 Hz), 7.30 (5 H, s)	67.8 (67.8)	6.10 (6.26)
(**107b**)	137—138 (hexane)	3 400, 1 680, 1 230, 885, 800	1.40 (9 H, s), 3.40 (1 H, d, *J* 1.5 Hz), 3.80 (1 H, d, *J* 1.5 Hz), 6.10 (1 H, br s, exchanges with D_2O), 7.30 (5 H, br s)	71.2 (71.2)	7.95 (7.82)
(**108b**)	Oil	1 655, 1 250, 915, 815	1.30 (3 H, s), 1.45 (3 H, s), 1.95 (4 H, m), 3.40 (1 H, s), 3.55 (4 H, m)		
(**109b**)	Oil	1 650, 1 230, 900, 815	0.95 (3 H, s), 1.05 (3 H, s), 1.65 (1 H, m), 1.95 (4 H, m), 2.95 (1 H, dd, *J* 6.5 and 2 Hz), 3.35 (1 H, d, *J* 2 Hz), 3.50 (4 H, m)	M^+, 183.1259 $C_{10}H_{17}NO_2$ requires 183.1259	
(**110b**)	Oil	1 650, 1 230, 915, 830	1.10 (7 H, m), 2.00 (4 H, m), 2.95 (1 H, dd, *J* 9.5 and 5 Hz), 3.70 (5 H, m)	M^+, 183.1256 $C_{10}H_{17}NO_2$ requires 183.1259	

* *cis*-Epoxy amide contains 11% *trans*-epoxy amide arising from epoxidation of *trans*-amide present as impurity. See Table 5 and ref. 36.
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trans-*Phenyl* β-*Styryl Sulphone* (**87b**).—The method described by Smith and Davis[39] was utilised in the preparation of the title compound to give (**87b**), m.p. 73—75 °C (lit.,[39] 74—75 °C).

Phenyl Vinyl Sulphone (**87c**).—The procedure described by Paquette *et al.*[40] was used to give the title compound (**87c**), m.p. 66—67 °C (lit.,[39] m.p. 66—67 °C).

(−)-S-*Phenyl*-S-(2-*phenylvinyl*)-N-(p-*tolylsulphonyl*)*sulphoximine* (**89**).—The title compound was prepared from (+)-*S*-methyl-*S*-phenylsulphoximine[41,42] by the method of Edelmeier and Gais[43] to give the title compound, m.p. 130—132 °C; $[\alpha]_D^{23}$ −52° (*c*, 1.0; acetone) {lit.,[43] m.p. 134 °C; $[\alpha]_D^{25}$ −56° (*c* 1.5; acetone)}.

Epoxidation of α,β-*Unsaturated Sulphones and Sulphoximines* (**87**) *and* (**89**).—The general method of epoxidation described for α,β-unsaturated esters is utilised for the epoxidation of α,β-unsaturated sulphones and sulphoximines. Thus, an anhydrous

Table 8. Physical data for 2,3-epoxy ketones (**112**)—(**121**)

Epoxy ketone	M.p. (°C) (lit. m.p.)	$\nu_{max.}$/cm^{-1}	^{1}H N.m.r. (δ_H)
(**112**)	43—44 (hexane)	1 710, 1 220, 885, 760	1.20 (3 H, t, *J* 7 Hz), 2.65 (2 H, q, *J* 7 Hz), 3.65 (1 H, d, *J* 1.5 Hz), 4.10 (1 H, d, *J* 1.5 Hz), 7.45 (5 H, s)
(**113**)	45—46 petroleum	1 710, 1 220, 890, 760	0.95 (3 H, t, *J* 7.5 Hz), 1.70 (2 H, m), 2.50 (2 H, m), 3.50 (1 H, d, *J* 1.5 Hz), 3.95 (1 H, d, *J* 1.5 Hz), 7.35 (5 H, br s)
(**114**)	48—49 (hexane)	1 710, 1 260, 905, 740	0.9 (3 H, m), 1.5 (4 H, m), 2.45 (2 H, m), 3.50 (1 H, d, *J* 1.8 Hz), 4.00 (1 H, d, *J* 1.8 Hz), 7.30 (5 H, br s)
(**115**)	Oil	1 715, 890, 760	1.15—2.20 (8 H, m), 2.95 (1 H, m), 3.80 (1 H, d, *J* 1.5 Hz), 4.20 (1 H, d, *J* 1.5 Hz), 7.65 (5 H, s)
(**116**)	Oil	1 715, 890, 790	1.25 (9 H, s), 3.85 (2 H, s), 7.35 (5 H, s)
(**117**)	Oil	1 735, 1 255, 915, 885, 800, 755	4.15 (2 H, s), 6.55 (1 H, dd, *J* 3.6 and 1.5 Hz), 7.35 (5 H, br s), 7.45 (1 H, d, *J* 4 Hz), 7.70 (1 H, br s)
(**118**)	89—90 (90)[a]		
(**119**)	Oil	1 720, 1 250, 915, 800	0.9 (3 H, m), 1.20—1.60 (4 H, m), 2.40 (2 H, m), 2.95 (2 H, m), 3.45 (2 H, dd, *J* 4.5 and 3 Hz)
(**120**)	Oil	1 720, 1 250, 910, 820	3.00 (2 H, m), 4.15 (1 H, dd, *J* 4.5 and 3 Hz), 7.30—8.05 (5 H, m)
(**121**)	Oil	1 710, 1 235, 970, 850	0.95 (3 H, m), 1.10—1.65 (4 H, m), 1.35 (3 H, d, *J* 5 Hz), 2.40 (2 H, m), 3.20 (2 H, m)

[a] E. Weitz and A. Sheffer, *Chem. Ber.*, 1921, **54**, 2327.

solution of t-butyl hydroperoxide (4.85 M solution; 3.10 ml, 15.0 mmol, 1.5 equiv.) was added to freshly distilled THF (30 ml) at −78 °C under an atmosphere of argon, and this was followed by addition of BuLi (1.6 M solution in hexane; 6.60 ml, 11.0 mmol, 1.1 equiv.) and a solution of *trans*-phenyl-β-styryl sulphone (**87b**) (2.44 g, 10.0 mmol) in THF (10 ml). The reaction mixture was then stirred at −20 °C for 1 h after which solid sodium sulphite (*ca.* 1 g) was added to it and stirring continued for 15 min. The mixture was then diluted with ether (50 ml), filtered through celite, and concentrated under reduced pressure; flash chromatography of the residue afforded the epoxide (**88b**) (2.43 g, 90%) as a white solid, m.p. 102—104 °C (lit.,[23] m.p. 102—104 °C).

In a similar manner, the following epoxy sulphones were prepared; from (**87a**) the epoxide (**88a**) was obtained as a white solid (90%), m.p. 72.5—73.5 °C (Found: C, 64.3; H, 4.58. $C_{14}H_{12}SO_3$ requires C, 64.6; H, 4.65%); $\nu_{max.}$ 1 580, 1 315, 1 180, 915, and 820 cm^{-1}; δ_H(Me_2SO) 4.60 (1 H, d, *J* 3.8 Hz), 4.70 (1 H, d, *J* 3.8 Hz), 7.30 (5 H, s), and 7.58 (5 H, s); (**87c**) afforded the epoxide (**88c**) (90%) as a white solid, m.p. 43.5 °C (Found: C, 51.9; H, 4.38. $C_8H_8SO_3$ requires C, 52.2; H, 4.38%); $\nu_{max.}$ 1 580, 1 310, 1 225, 1 150, 885, and 800 cm^{-1}; δ_H 3.15 (1 H, dd, *J* 6 and 4.5 Hz), 3.36 (1 H, dd, *J* 6 and 4.5 Hz), 4.32 (1 H, dd, *J* 6 and 4.5 Hz, 7.69 (3 H, m), and 8.00 (2 H, m).

S-*Phenyl*-S-(trans-3-*phenyloxiran*-2-*yl*)-N-(p-*tolylsulphonyl*)*sulphoximine* (**90**).—The α,β-unsaturated sulphoximine (**89**) was treated in the same manner as described above. After the reaction mixture had been stirred at −20 °C overnight, work-up afforded the epoxide (**90**) in quantitative yield: flash chromatography of this gave a white solid (20%), m.p. 91—93 °C; $[\alpha]_D^{22}$ +121° (*c* 1.0 in acetone) (Found: C, 61.3; H, 4.7. $C_{21}H_{19}NO_4S_2$ requires C, 61.0; H, 4.63%); $\nu_{max.}$ 1 595, 1 310, 1 245, 1 150, 860, and 810 cm^{-1}; δ_H 2.51 (3 H, s), 4.48 (1 H, d, *J* 1.5 Hz), 4.67 (1 H, d, *J* 1.5 Hz), and 7.60 (14 H, m).

Reaction of 2,3-*Epoxy Amides with Alkyl-lithiums: Preparation of* 2,3-*Epoxy Ketones*.—A solution of methyl-lithium (1.4 M solution in ether; 4.95 ml, 6.92 mmol, 1.5 equiv.) was added slowly to a solution of the epoxy amide (**103b**) (1.00 g, 4.61 mmol) in dry THF (20 ml) at −78 °C under an atmosphere of nitrogen, and the resulting solution was stirred at −78 °C for 15 min. The reaction was quenched by the addition of water (20 ml), the organic layer was separated, and the aqueous phase was extracted with ether (3 × 15 ml). The organic layers were combined, dried ($MgSO_4$), and evaporated under reduced pressure. Flash chromatography of the residual oil (petroleum–ether, 1:1) afforded 2,3-epoxy-3-phenylbutan-2-one (**111**) (0.47 g, 69%) as a white solid, which upon crystallisation from hexane afforded white needles, m.p. 45 °C (lit.,[44] m.p. 45 °C).

Similarly, the epoxy ketones (**112**)—(**121**) were prepared (see Table 3). Physical data for the epoxy ketones prepared in this manner are given in Table 8.

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