Dynamic Stereochemistry of Imines and Derivatives. Part 18.[1] Photosynthesis and Photoracemization of Optically Active Oxaziridines

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Optically active oxaziridines have been synthesized with a maximum optical yield of 31% by photoisomerization ($\lambda > 300$ nm) of achiral aldo- and keto-nitrones in the presence of the chiral solvent (+)-(*S*) or (−)-(*R*)-2,2,2-trifluoro-1-phenylethanol. Photorearrangement of chiral nitrones to optically active oxaziridines was found to occur in achiral solvents with an optimum diastereoisomeric excess of 20%. Temperature, solvent and substituent effects upon the degree of asymmetric synthesis of chiral oxaziridines from the corresponding nitrone isomers have been examined.

Photoracemization and photoepimerization (λ 254 nm) of oxaziridines bearing a *p*-nitrophenyl substituent have been observed. Mechanisms involving a nitrone intermediate, and reversible N–O bond cleavage or photoinduced pyramidal nitrogen inversion are proposed.

The oxaziridine system was first demonstrated to be chiral by a kinetic resolution method using the optically active base brucine.[2] This observation enabled Emmons to distinguish between the isomeric achiral nitrone and chiral oxaziridine structures proposed for these compounds. Asymmetric synthesis, which was initially achieved using the chiral oxidant (+)-peroxycamphoric acid,[3] provides a much more convenient and general route to oxaziridines. A wide range of optically active oxaziridines, including several which could be obtained in optically pure form, are now available using the chiral peroxycarboxylic acid[3–15] or the chiral peroxyimidic acid[16] route. Optically active oxaziridines have also been synthesized by the imine–peroxy acid route using either chiral imines[12–15,17–26] or chiral solvents.[27–28]

The early interest in optically active oxaziridines resulted initially from their possession of a configurationally stable (non-inverting) nitrogen atom. Thermal racemization[8–9] or epimerization[10] studies thus provided information about the pyramidal nitrogen inversion process. The ability of oxaziridines to transfer an oxygen atom to phosphines,[2] sulphide,[22,24,29,30] and olefins[25,31] has recently been extended to optically active oxaziridines thus producing a neutral chiral oxidant. Oxaziridines have also been proposed as intermediates in biological systems.[32–35]

While the imine–peroxy acid route to oxaziridines is the most widely used synthetic procedure, a large number of oxaziridines have also been produced by photoisomerization of nitrones.[36–39] Until the preliminary report of the present work,[40] optically active oxaziridines had not been produced by this method. Here we discuss the synthesis of optically active oxaziridines using chiral nitrones or chiral solvents more comprehensively.

The nitrone photorearrangement synthetic pathway to oxaziridines has several advantages over the imine–peroxy acid reaction:

(a) The reaction occurs under neutral low temperature conditions and often requires only the removal of solvent to yield the product. Oxaziridines may be acid- or base-sensitive or thermally unstable and the nitrone photoisomerization route is of value since it avoids these conditions.

(b) Oxidation of imines by peroxyacids may occasionally yield nitrones rather than oxaziridines and the photochemical method may be the only available synthetic route.

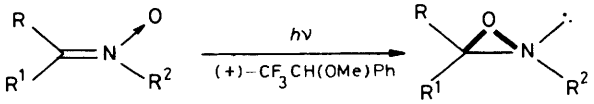
The use of chiral solvents in asymmetric synthesis has generally been limited by the low optical yields obtained (0—10%[41]). One exception was the photochemical reduction of acetophenone at −72 °C in the presence of the optically active solvent (+)-1,4-bis(dimethylamino)-2,3-dimethoxybutane which gave a product having *ca.* 24% enantiomeric excess.[42] Optically active 2,2,2-trifluoro-1-phenylethanol has been found to solvate the enantiomers of sulphoxides, phosphine oxides, and amine oxides thus allowing them to be distinguished by n.m.r. analysis.[43–46] The similarity between tertiary amine *N*-oxides and nitrones (imine *N*-oxides) prompted an examination of the photoisomerization of nitrones to oxaziridines in this solvent.

The range of oxaziridines and nitrones studied are shown in Table 1. A typical experiment involved the addition of nitrone, chiral alcohol solvent, and fluorotrichloromethane to a standard Pyrex n.m.r. tube maintained at the required temperature followed by exposure to u.v. light which was produced by a medium-pressure lamp (>300 nm). Using fluorotrichloromethane as diluent, it was possible to irradiate the homogeneous liquid sample at a low temperature (−78 °C). However, in some cases low solubility was a problem at this temperature and thus comparative experiments between nitrones having different *para* substituted phenyl groups were carried out at −40 °C. Reaction progress was monitored by n.m.r. analysis and the product oxaziridines were separated from the chiral alcohol and unchanged nitrone by preparative t.l.c. Total thermal racemization of the optically active oxaziridine products (**2d**) and (**2e**) occurred by heating at 55 and 120 °C respectively (by the method previously reported[8]) thus confirming that all traces of chiral solvent had been removed. The expected dependence of optical yield upon temperature was evident from the results indicated in Table 1. The oxaziridine (**2d**) was obtained with an enantiomeric excess of approximately 5—31% over the temperature range of +25 °C to −78 °C. As expected, a similar magnitude and opposite sign of $[\alpha]_D$ values was obtained using either (+)-(*S*)-or (−)-(*R*)-2,2,2-trifluoro-1-phenylethanol.

The nature of substituents on the nitrone appeared to have a marked effect on the optical yield of product oxaziridines. Thus, substitution of the less bulky *N*-isopropyl group for an *N*-t-butyl group led to a corresponding decrease in optical purity of the oxaziridines (**2d**) (29—31% at −78 °C, 15% at −40 °C) and (**2e**) (20% at −78 °C, 11% at −40 °C). In general, the presence of bulkier substituents on the ring carbon atoms, e.g. (**2d**) and (**2e**), was also associated with higher optical yields.

Based upon the solute–solvent interactions previously proposed for amine oxides, phosphine oxides and sulph-

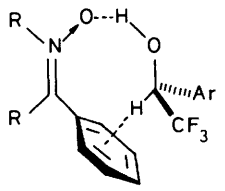
Table 1. Photochemical isomerization of nitrones to oxaziridines in the chiral solvent (+)-(S)-2,2,2-trifluoro-1-phenylethanol



	R	R^1	R^2	Temperature (°C)	Time (h)	% Yield[a]	$[\alpha]_D$/°[b]	% Optical yield
(2a)	Ph	H	Bu^t	−40	31	100	+9.9	11.5[c]
(2b)	4-BrC_6H_4	H	Bu^t	−38	39	95	+1.0	1.4[c]
(2c)	4-$NO_2C_6H_4$	H	Bu^t	−40	65	63	−0.4	0.4[d]
(2c)	4-$NO_2C_6H_4$	H	Bu^t	−78	23	24	−5.6	5.6[d]
(2d)	Ph	Ph	Bu^t	−40	27	100	+39.2	15.2[e]
(2d)	Ph	Ph	Bu^t	−78	10	50	+75.9	29[e]
(2d)	Ph	Ph	Bu^t	−78	14	50	−80.9[f]	31[e]
(2d)	Ph	Ph	Bu^t	+25	5	40	+12.7	5[e]
(2e)	Ph	Ph	Pr^i	−40	73	90	+21.1	11.0[e]
(2e)	Ph	Ph	Pr^i	−78	33	34	+38.8	20.0[e]

[a] Conversion of nitrone into oxaziridine by n.m.r. analysis. [b] Purified by preparative t.l.c. and determined in $CHCl_3$ solution. [c] Ref. 46. [d] Ref. 10. [e] Ref. 9. [f] Obtained using (−)-2,2,2-trifluoro-1-phenylethanol.

oxides,[43–45] hydrogen bonding interactions would be expected to occur between the acidic hydroxy group and the basic oxygen atom of the nitrone. A secondary interaction would also be anticipated between the electron deficient carbinyl proton and the basic π electron clouds of the aryl rings:

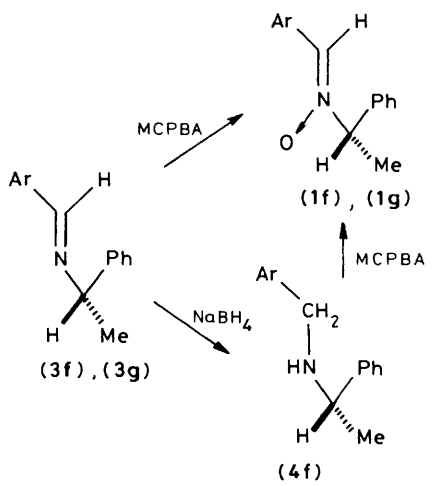


Since the absolute stereochemistry of the oxaziridines (**2a**)—(**2f**), the nature of the solute–solvent interactions, and the mechanism of nitrone to oxaziridine photorearrangement have not been unequivocally established, it is at present difficult to provide a detailed analysis of transition state geometry to account for the preferential formation of one enantiomer.

The decrease in optical purity of oxaziridines derived from aldonitrones across the series having different *para*-phenyl substitutents, *i.e.* H (**2a**) (11.5%), Br (**2b**) (1.4%), and NO_2 (**2c**) (0.4%), would support the view that the preferred solvation of nitrones is of a similar type to that proposed for amine oxides. The presence of a substituent atom bearing lone pairs (*e.g.* Br) or a polar N–O bond (*e.g.* NO_2) would be expected to give alternative types of solute–solvent interactions and would account for the decreased efficiency of the asymmetric synthesis. This effect may also explain the chemical shift difference (Δδ) of the Bu^t signals in the n.m.r. spectrum of the (+) and (−) enantiomers of oxaziridines (**2a**) and (**2c**). The oxaziridine (**2a**) having a 4-H atom present, gave a value of 0.041 p.p.m. for Δδ while oxaziridine (**2c**) gave a lower Δδ value (0.013 p.p.m.), due to the presence of a 4-NO_2 substituent. At this stage of the discussion the possibility of a small degree of photoracemization of the oxaziridine (**2c**) cannot be excluded (see later).

The maximum optical yield found in the photochemical rearrangement of nitrones to oxaziridines in the presence of a chiral solvent (31% e.e.) is comparable to, or better than, values obtained using the same (or related) chiral solvent systems in the imine–peroxy acid reaction. Optical yields up to 28% were obtained for oxaziridine (**2b**) resulting from the imine–peroxy acid reaction in the presence of (−)-(*R*)-2,2,2-trifluoro-1-(1-naphthyl)ethanol.[28] Recent attempts to produce optically active oxaziridines by the photoisomerization of nitrones in a chiral environment, *e.g.* a cholesteric liquid crystal medium[47] or a cyclodextrin in the presence of amino acids[48] have resulted in low optical yields (< 2%).

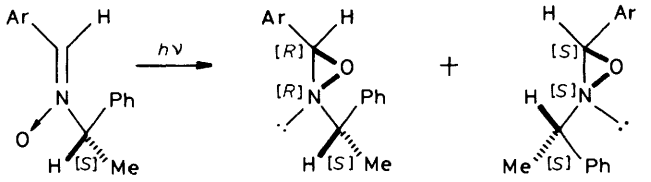
An alternative approach to obtaining optically active oxaziridines by the nitrone photorearrangement method would involve the use of nitrones bearing a chiral substituent. The degree of asymmetric synthesis induced at the new chiral nitrogen centre might then be deduced directly from the diastereoisomeric excess obtained from a n.m.r. analysis of the oxaziridine product mixture. The optically pure nitrone (**1f**), ($[\alpha]_D$ +55°) was synthesized by reduction of the parent (+) imine (**3f**) to the secondary amine (**4f**), ($[\alpha]_D$ −39.9°) followed by oxidation to the nitrone (**1f**). (Schemes 1 and 2). Photoisomerization of the nitrone (**1f**) at 20 °C was studied using a range of solvents to yield only the *trans*-oxaziridines *RRS*-(**2f**) and *SSS*-(**2f**) (Scheme 2).* The latter optically active



Ar≡*p*-BrC_6H_4(**1f**),(**3f**),(**4f**) Ar≡Me_5C_6(**1g**),(**3g**),(**4g**)

Scheme 1.

* The *cis*—*trans* nomenclature used for oxaziridines and nitrones in this study refers to the relationship between the *C*-aryl and *N*-alkyl substituents.



(1f) Ar ≡ *p*-BrC_6H_4 *RRS*-(2f) *SSS*-(2f)

(1g) Ar ≡ Me_5C_6 *RRS*-(2g) *SSS*-(2g)

Scheme 2.

Table 2. Photoisomerization products of the nitrones (**1g**) and (**1h**) at 20 °C[a,b]

Nitrone	Solvent	% *RRS*-(2)	% SSS-(2)	% Diastereoisomeric excess[a]
(**1f**)	$CDCl_3$	44	56	12
(**1f**)	C_6D_5N	46	54	8
(**1f**)	C_6D_6	45	55	10
(**1f**)	$(CD_3)_2CO$	48	52	4
(**1f**)	$(CD_3)_2SO$	40	60	20
(**1f**)	CD_3CN	44	56	12
(**1f**)	CD_3OD	46	54	8
(**1g**)	$CDCl_3$	50	50	0

[a] Diastereoisomeric excess determined by n.m.r. analysis at 250 MHz. [b] Irradiated using a medium pressure Hanovia u.v. lamp (>300 nm).

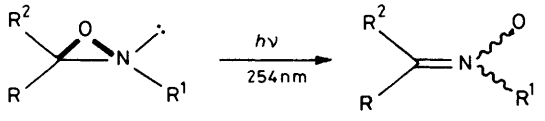
of the parent imine (**3g**, $[\alpha]_D$ −13.7°) (Scheme 1). Since the oxaziridines *RRS*-(**2g**) and *SSS*-(**2g**) formed by photorearrangement of (**1g**) had not previously been reported, they were separated by chromatography and characterized. As observed in the photoisomerization of (**1f**), the product oxaziridines from (**1g**) were found to have the *trans* configuration but, in contrast, no diastereoisomeric excess of either *RRS*-(**2g**) or *SSS*-(**2g**) was observed. On the basis of the absolute stereochemistry assigned to oxaziridines *RRS*-(**2f**) and *SSS*-(**2f**) from *X*-ray crystallographic studies and n.m.r. correlation,[19] oxaziridines (**2g**) may be tentatively assigned as *RRS*-(**2g**) ($[\alpha]_D$ −97.6°) and *SSS*-(**2g**) ($[\alpha]_D$ +62.6°).

It is noteworthy that only the *trans*-oxaziridine diastereoisomers (**2f**) and (**2g**) were obtained from the photoisomerization since previous photochemical studies have shown that both *cis*- and *trans*-isomers may be formed from the *trans*-aldonitrones bearing a 4-nitrophenyl group.[38,39]

Oxaziridines (**2d**) and (**2e**) formed by photoisomerization of the nitrones (**1d**) and (**1e**) were found to have $\lambda_{max.}$ values of <210 nm (Table 3) and thus a decrease in optical yield by a photoracemization process using u.v. light of wavelength >300 nm appeared unlikely. Nevertheless, this possibility has now been examined using the optically active oxaziridines (**2c**), (**2h**), (**2i**), (**2j**), and (**2k**) ($\lambda_{max.}$ 267—276 nm) and lower wavelength radiation (254 nm) (Tables 4—5).

Preliminary studies[6] had indicated that *cis*-oxaziridines, *e.g.* *c*-(**2i**), were able to photoisomerize to *trans*-oxaziridines while the reverse reaction did not occur. As part of the present study a

Table 3. Photoisomerization of oxaziridines to nitrones in $CDCl_3$ solution



	R	R[1]	R[2]	Time (h)	% Nitrone ( )[a]	Oxaziridine[b] $\lambda_{max.}$	Oxaziridine[b] $\varepsilon_{max.}$
t-(**2h**)	H	Me	*p*-$NO_2C_6H_4$	17	10 (*t*)	270	12 200
c-(**2h**)	4-NO_2·C_6H_4	Me	H	17	22[c] (*t*)	268	11 100
t-(**2i**)	H	Pr[i]	*p*-$NO_2C_6H_4$	14	21 (*t*)	270	12 600
c-(**2i**)	4-NO_2·C_6H_4	Pr[i]	H	5	35[c] (*t*)	270	14 300
t-(**2c**)	H	Bu[t]	*p*-$NO_2C_6H_4$	23	34 (*t*)	273	11 600
t-(**2j**)	Me	Bu[t]	*p*-$NO_2C_6H_4$	21	27 (*c*/*t*)	267	13 300
c-(**2j**)	4-NO_2·C_6H_4	Bu[t]	Me	26	27[c] (*c*/*t*)	275	7 100
(**2k**)	4-NO_2·C_6H_4	Bu[t]	*p*-$NO_2C_6H_4$	7	34	276	12 100
(**2d**)	Ph	Bu[t]	Ph	44	0	205	13 600
t-(**2a**)	H	Bu[t]	Ph	168	0	249[d]	930[d]
t-(**2e**)	H	Pr[i]	Ph			207	15 000

[a] Stereochemistry determined by ^1H n.m.r. analysis at 90 MHz. [b] Determined as a 10^{-4}M solution in MeCN. [c] Accompanied by the formation of the isomeric *trans* oxaziridines. [d] Values taken from ref. 2.

oxaziridines and the isomeric *cis*-isomers have previously been synthesized by the imine–peroxy acid route.[19] In the present study it was unnecessary to separate the product mixture of optically pure diastereoisomers *RRS*-(**2f**) and *SSS*-(**2f**) since they were readily distinguishable by n.m.r. analysis[19] (Table 2). A relatively modest diastereoisomeric excess of the *SSS*-(**2f**) isomer (4—20% d.e.) was obtained in comparison with the excess (48%) of compound *RRS*-(**2f**) found by oxidation of the parent chiral imine at 0 °C.[19] This asymmetric synthesis differed from the earlier study using a chiral solvent since no change in optical yield was found over the temperature range +20 °C to −40 °C.

Nitrone (**1g**) was obtained directly by peroxy acid oxidation

more detailed examination of this *cis*—*trans* isomerization has been carried out on optically active oxaziridines (**2c**), (**2h**), (**2i**), and (**2j**) (Table 3). Thus it was again observed that *cis* oxaziridine *c*-(**2i**) was isomerized to the *trans*-isomer *t*-(**2i**) but was also accompanied by *trans* nitrone formation. By contrast, the *trans*-oxaziridines *t*-(**2h**), *t*-(**2i**), and *t*-(**2c**) were found to isomerize to the corresponding *trans*-nitrones only. Nitrone formation was also observed when oxaziridines *c*-(**2j**), *t*-(**2j**), and (**2k**) were irradiated while oxaziridines *t*-(**2a**) and *t*-(**2d**) appeared to be unchanged. This photochemical reaction provides a convenient synthetic route to nitrones such as (**1j**) and (**1k**) which are difficult to obtain by other methods. The absence of nitrone products (**1a**) and (**1d**) after u.v. irradiation of

Table 4. Photoracemization (254 nm) of oxaziridines in chloroform solution

Compd.	Time (h)	Decrease in $[\alpha]_D/^0$ value[a] Before	After
(**2k**)	74	−60.2	0
t-(**2h**)	11	−17.2	−12.8
t-(**2i**)	8	−12.0	−9.7
c-(**2i**)	5	−7.4	−7.4
t-(**2c**)	8	−44.8	−28.1
t-(**2j**)	20	+8.5	+1.6
	20	+11.8	+6.2
c-(**2j**)	8	−40.1	−22.8
	6	−32.7	−23.7

[a] Purified by column chromatography and determined in $CHCl_3$ solution.

oxaziridines (**2a**) and (**2d**) may be attributed to weak absorption in the region of 254 nm. Since photoisomerization of nitrones to oxaziridines at 254 nm is also known to occur, the process appeared to be reversible for oxaziridines (**2c**), (**2h**), (**2i**), (**2j**), and (**2k**) and to provide a mechanism for photoracemization and photoepimerization.

Irradiation of the oxaziridines indicated in Table 4 generally led to either complete or partial racemization as outlined in a preliminary report of this work.[49] The degree of racemization, determined after chromatographic separation of the nitrone, varied according to the period of irradiation. The oxaziridine (**2k**) possessed one chiral centre and was the only compound in Table 4 to be totally racemized. Racemization of (**2k**) could in principle occur *via* an achiral nitrone intermediate or by an inversion of configuration at nitrogen. Since the irradiation was carried out at ambient temperature, when a thermal nitrogen inversion process would have been relatively slow ($\Delta G^{\ddagger}_{54\,°C}$ = 25.9 kcal mol^{-1} ref. 50), it is unlikely that racemization could have been accounted for by this mechanism.

The optically active *trans*-oxaziridines *t*-(**2h**), *t*-(**2i**), and *t*-(**2c**), recovered after exposure to u.v. light, were all found to have partially racemized. By contrast the *cis*-oxaziridine *c*-(**2i**), after similar treatment, gave no indication of racemization (Table 4). A pyramidal inversion mechanism involving epimerization at nitrogen would not account for these observations and the results appear to be consistent with a photoracemization process occurring *via* a nitrone intermediate. The latter intermediate appeared to be formed reversibly from *trans*-oxaziridines and irreversibly from *cis*-oxaziridines.

The decrease in optical rotation after u.v. irradiation of oxaziridines *t*-(**2j**) and *c*-(**2j**) would again appear to be consistent with a photoracemization mechanism involving a nitrone intermediate, *i.e.* photolysis of the oxaziridine ring C–O bond and concomitant racemization at *both* chiral centres.

Studies on the photoinduced epimerization of the optically active oxaziridines *c*-(**2i**) to *t*-(**2i**), *c*-(**2j**) to *t*-(**2j**), and *t*-(**2j**) to *c*-(**2j**) provided further information on the mechanism of photoracemization (Table 5). The (−)-(*cis*-oxaziridines *c*-(**2i**) and *c*-(**2j**) yielded racemic *trans*-oxaziridines [*t*-(**2i**) and [*t*-(**2j**) respectively] after photolysis, as anticipated on the assumption that the stereomutation occurred *via* a nitrone intermediate. Photolysis of optically active *trans*-oxaziridine *t*-(**2j**) led to the formation of *cis*-oxaziridine *c*-(**2j**) of lower optical purity, *but of opposite sign of rotation.* Thermal epimerization of optically active oxaziridine *t*-(**2j**) to *c*-(**2j**) has been observed to occur at 100 °C without oxaziridine bond cleavage [34% *trans* isomer *t*-(**2j**) present at equilibrium, 100 °C[10]] and with a reversal in sign [$\Delta G^{\ddagger}_{t\text{-}(2j)\longrightarrow c\text{-}(2j)}$ 25.4 kcal mol^{-1} at 100 °C[10]]. If a thermal pyramidal inversion mechanism had occurred under the

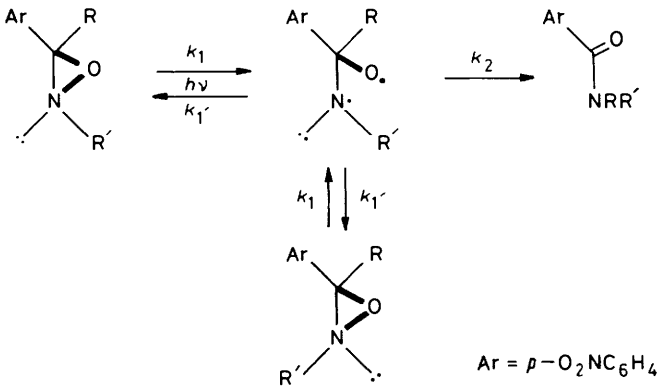
Table 5. Photoepimerization (254 nm) of oxaziridines *c*-(**2i**), *c*(**2j**) and *t*-(**2j**) in chloroform solution

Reactant	$[\alpha]_D/^0$[a]	% E.e.	Product[b]	$[\alpha]_D/^0$[a]	% E.e.
c-(**2i**)	−7.4	9	*t*-(**2i**)	0	0
c-(**2j**)	−40.1	49	*t*-(**2j**)	0	0
	−32.7	50		0	0
t-(**2j**)	+8.5	10	*c*-(**2j**)	−2	1
	+12	15		−8	5
	+82[c]	100		−160[c]	100

[a] In $CHCl_3$ solution. [b] Separated by column chromatography. [c] Thermal epimerization results at 100 °C in C_2Cl_4 solution as reported in ref. 10.

photochemical conditions (ambient temperature) a similar sign reversal would have been observed for the interconversion of *c*-(**2j**)—*t*-(**2j**) [$\Delta G^{\ddagger}_{c\text{-}(2j)\longrightarrow t\text{-}(2j)}$ 25.85 kcal mol^{-1} at 100 °C]. On this basis it is improbable that a thermally induced pyramidal inversion mechanism can account for the transformation of *t*-(**2j**) to *c*-(**2j**) under the photochemical conditions employed.

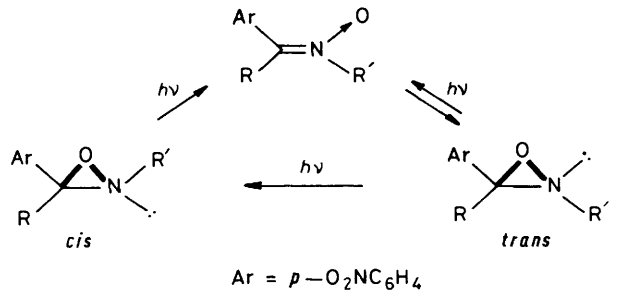
Photoepimerization at the oxaziridine nitrogen might conceivably occur by a light-catalysed pyramidal inversion process. There are precedents in the literature for a photoinversion process of this type occurring at sulphur in optically active diaryl and alkyl aryl sulphoxides.[51,52] It was suggested that the inversion could occur without bond cleavage by transfer of energy from an electronically excited state to the appropriate vibrational mode.[51,52] Alternatively, the epimerization at nitrogen could be brought about by a reversible photochemical cleavage of the oxaziridine N–O bond (Scheme 3). Oxaziridines are known to undergo photochemical N–O



Scheme 3.

bond cleavage to give amides.[53] The reaction is thought to take place in a stepwise manner *via* an acyclic diradical intermediate (Scheme 3).[53] The first step in this process, if reversible, would provide a mechanism for photoepimerization at nitrogen. Only small amounts of amide were detected by n.m.r. spectroscopy following the photoracemization experiments reported in Table 4, therefore if epimerization occurs by this mechanism it follows that $k_1' > k_2$ in Scheme 3. Reversible cleavage of the oxaziridine C–N bond to give a carbonyl imine[54] [*p*-$NO_2C_6H_4C(R) = \overset{+}{O}\text{-}\overset{-}{N}R'$] would have led to racemization rather than epimerization of the recovered oxaziridine (R ≠ *p*-$NO_2C_6H_4$).

The thermal equilibrium position, *t*-(**2j**):*c*-(**2j**) = 34:66% at 100 °C, may not be at all relevant to the photochemical



Scheme 4.

equilibrium. If photoinduced epimerization proceeds by vibrational decay of the excited state, it is unlikely that the vibrational energy will be transferred with equal efficiency to the epimerizing bond for both the *cis*- and *trans*-oxaziridine isomers. The photochemical equilibrium will thus be different from the thermal equilibrium.*

The reaction sequence shown in Scheme 4 may thus provide a rationalization of the photoracemization and photoepimerization results given in Tables 4 and 5.

It is noteworthy that only optically active *cis*-oxaziridine *c*-(**2i**) isomerizes irreversibly to the corresponding nitrone which in turn reversibly isomerizes to the *trans* oxaziridines *t*-(**2i**). The major reaction pathway for photoisomerization of *trans* oxaziridines, *t*-(**2h**), *t*-(**2i**), and *t*-(**2c**), appears to be *via* a nitrone intermediate. *trans*-Oxaziridine *t*-(**2j**) would also appear to racemize by this mechanism but was also found to epimerize to *cis*-oxaziridine *c*-(**2j**). The inability of *c*-(**2j**) to photoepimerize to *t*-(**2j**) was surprising but may be due to the higher wavelength ($\lambda_{max.}$) and lower intensity of absorption ($\varepsilon_{max.}$) of *c*-(**2j**) (275 nm; 7 100) compared with *t*-(**2j**) (267 nm; 13 300).

In conclusion, it would appear probable that the degree of optical purity obtained during photochemical asymmetric synthesis of oxaziridines (**2a**), (**2b**), (**2d**), and (**2e**) will be unaffected by photoracemization. The possibility of photoracemization occurring during the synthesis of oxaziridine (**2c**) however, cannot be totally excluded. Oxaziridines bearing a *p*-nitrophenyl substituent on the ring carbon atom appear to racemize *via* a nitrone intermediate when irradiated at 254 nm. A photoinduced pyramidal nitrogen inversion process or a reversible N–O bond cleavage could account for the observed epimerization of oxaziridine *t*-(**2j**) to *c*-(**2j**), and may contribute to the racemization of oxaziridine (**2k**) where nitrogen is the only chiral centre.

Experimental

^{1}H N.m.r. spectra were recorded at *ca.* 30 °C on 60 MHz (Varian A60), 90 MHz (Bruker WH-90) or 250 MHz (Bruker WH-250) spectrometers with $CDCl_3$ as solvent (unless specified otherwise) and tetramethylsilane as reference. Optical rotations were recorded using Perkin-Elmer Automatic polarimeters (Model 141 or 241) and $CDCl_3$ solvent at concentrations of *ca.* 10 mg/cm^3.

Analytical t.l.c. was carried out on plastic sheets coated with Kieselgel $60F_{254}$ (Merck) while preparative t.l.c. used glass plates (40 cm × 20 cm) coated with Kieselgel PF_{254} (Merck). Crassfield Sorbsil 200—300 mesh silica gel was used for column chromatography. (−)-(*R*) and (+)-(*S*)-2,2,2-Trifluoro-1-phenylethanol were commercially available (Burdick and Jackson). Nitrones (**1a**),[2] (**1c**),[2] (**1d**),[55] (**1e**),[9] (**1h**),[56] (**1i**),[2] (**1j**),[56] and (**1k**)[55] and oxaziridines (**2a**),[2] (**2b**),[57] (**2c**),[2] (**2d**),[8,9] (**2e**),[8,9] (**2f**),[19] (**2h**),[10] (**2i**),[10] (**2j**),[10] and (**2k**)[50] were synthesized by the literature methods. The optically active oxaziridines were prepared by (+)-peroxycamphoric acid oxidation of the parent imines by methods previously described.[5,8]

Ether refers to diethyl ether.

N-(*p-Bromobenzylidene-t-butylamine* N-*Oxide* (**1b**).—Compound (**1b**) was obtained by heating the oxaziridine (**2b**) in refluxing toluene for 33 h. Recrystallization of the product from benzene–pentane gave the nitrone (**1b**) (60% yield), m.p. 61—62 °C (Found: C, 51.7; H, 5.7; N, 5.3. $C_{11}H_{14}BrNO$ requires C, 51.6; H, 5.5; N, 5.5%); δ_H (60 MHz) 1.61 (9 H, s, Bu^t), 7.4 (1 H, s, CH=N), 7.45 (2 H, d, *J* 8 Hz, ArH), and 8.05 (2 H, d, *J* 8 Hz, ArH).

N-[*Bis*-(*p-nitrophenyl*)*methylene*]-*t-butylamine* N-*oxide* (**1k**).—The nitrone (**1k**) was obtained by photoisomerization of the oxaziridine (**2k**) under conditions used in the photoracemization and photoepimerization studies. The product was obtained in 34% yield and purified by recrystallization from benzene–pentane, m.p. 106—107 °C (Found: C, 59.4; H, 5.0; N, 12.3. $C_{17}H_{17}N_3O_5$ requires C, 59.5; H, 5.0; N, 12.2%); δ_H (60 MHz) 1.48 (9 H, s, Bu^t), and 7.3—8.4 (8 H, m, ArH).

(S)-(−)-N-(*p-Bromobenzyl*)-1-*phenylethylamine* (**4f**).—The amine (**4f**) was obtained in 77% yield by sodium borohydride reduction of (*S*)-(+)-*N*-(*p*-bromobenzylidene)-1-phenylethylamine (**3f**)[20] as previously reported for the synthesis of other secondary amines,[55] b.p. 140—142 °C/1.0 mmHg, $[\alpha]_D$ −39.9° ($CHCl_3$), (Found: C, 62.0; H, 5.8; N, 4.6. $C_{15}H_{16}NBr$ requires C, 62.1; H, 5.6; N, 4.8%), δ_H (90 MHz) 1.32 (3 H, d, *J* 6.6 Hz, CH*Me*), 1.52 (1, br s, NH), 3.52 (2 H, s, CH_2), 3.74 (1 H, q, *J* 6.6, C*H*Me), and 7.03—7.54 (9 H, m, ArH).

(S)-(+)-N-(*p-Bromobenzylidene*)-1-*phenylethylamine* N-*Oxide* (**1f**).—The nitrone (**1f**) was synthesized by *m*-chloroperbenzoic acid oxidation of the secondary amine (**4f**) in CH_2Cl_2 by the general route reported previously.[55] After recrystallisation from benzene–light petroleum (b.p. 40—60 °C) the nitrone (**1f**) was isolated in 49% yield, m.p. 110—112 °C, $[\alpha]_D$ +55.3° ($CHCl_3$), (Found: C, 58.6; H, 4.6; N, 4.5. $C_{15}H_{14}BrNO$ requires C, 59.2; H, 4.6; N, 4.6%); δ_H (90 MHz) 1.87 (3 H, d, *J* 6.8 Hz, CH*Me*), 5.16 (1 H, q, *J* 6.8 Hz, C*H*Me), 7.31—7.57 (8 H, m, ArH and CH=N), and 8.09 (2 H, d, *J* 8.5 Hz, ArH).

(S)-(−)-N-(*Pentamethylbenzylidene*)-1-*phenylethylamine* (**3g**).—The imine (**3g**) was obtained by condensation of pentamethylbenzaldehyde with (*S*)-(−)-1-phenylethylamine (yield 92%), m.p. 58—60 °C (pentane), $[\alpha]_D$ −13.7° ($CHCl_3$), (Found: C, 86.2; H, 8.9; N, 5.1. $C_{20}H_{25}N$ requires C, 86.0; H, 9.0; N, 5.0%) δ_H (90 MHz) 1.63 (3 H, d, *J* 6.6 Hz, CH*Me*), 2.18 (15 H, s, 5 × Me), 4.59 (1 H, q, *J* 6.6 Hz, C*H*Me), 7.25—7.42 (5 H, m, ArH), and 8.70 (1 H, s, CH=N).

(S)-(+)-N-(*Pentamethylbenzylidene*)-1-*phenylethylamine* N-*Oxide* (**1g**).—The nitrone (**1g**) was obtained by *m*-chloroperbenzoic acid oxidation of imine (**3g**) in CH_2Cl_2 at ambient temperature. Recrystallization from benzene–light petroleum gave (**1g**) in 92% yield, m.p. 193—196 °C, $[\alpha]_D$ +59.4 ° ($CHCl_3$), (Found: C, 80.9; H, 8.7; N, 4.6. $C_{20}H_{25}NO$ requires C, 81.3; H, 8.5; N, 4.7%), δ_H (90 MHz) 1.92 (3 H, d, *J* 7.1 Hz, CH*Me*), 2.04 (6 H, s, 2 × Me), 2.16 (6 H, s, 2 × Me), 2.19 (3 H, s, Me), 5.24 (1 H, q, *J* 7.1 Hz, C*H*Me), 7.25 (1 H, s, C*H*=N), and 7.34—7.59 (5 H, m, ArH).

* A referee has suggested that the isomerization of the oxaziridine to nitrene in the presence of u.v. light might have occurred by a process of reversible electron transfer between the oxaziridine nitrogen lone pair and the *p*-nitrophenyl moeity. From the evidence available this possibility cannot be excluded.

(2R,3R)-2[(S)-1′-*Phenylethyl*]-3-(*pentamethylphenyl*)-*oxaziridine RRS*-(**2g**) and (2S,3S)-2-[(S)-1′-*phenylethyl*]-3-(*pentamethylphenyl*)*oxaziridine SSS*-(**2g**).—The oxaziridines *RRS*-(**2g**) and *SSS*-(**2g**) were obtained as a mixture by photoisomerization of the nitrone (**1g**), m.p. 128—130 °C (Found: M^+, 295.1931. $C_{20}H_{25}NO$ requires *M*, 295.1936). The mixture was separated by preparative t.l.c. on silica-gel (CH_2Cl_2 as eluant) to give *RRS*-(**2g**), m.p. 142—147 °C, R_F 0.63, $[\alpha]_D$ −97.6° ($CHCl_3$); δ_H (250 MHz) 1.68 (3 H, d, *J* 6.7 Hz, CH*Me*), 2.18 (6 H, s, 2 × Me), 2.21 (3 H, s, Me), 2.31 (6 H, s, 2 × Me), 3.58 (1 H, q, *J* 6.9 Hz, C*H*Me), 4.88 (1 H, s, CH), and 7.28—7.48 (5 H, m, ArH). Subsequently *SSS*-(**2g**) was eluted, m.p. 96—99 °C, R_F 0.51, $[\alpha]_D$ +62.6°, δ_H (250 MHz) 1.68 (3 H, d, *J* 6.6 Hz, CH*Me*), 1.86 (6 H, s, 2 × Me), 2.07 (6 H, s, 2 × Me), 2.15 (3 H, s, Me), 3.29 (1 H, q, *J* 6.6 Hz, C*H*Me), 4.96 (1 H, s, CH), and 7.36—7.50 (5 H, m, ArH).

General Procedure for the Photoisomerization of Nitrones to Oxaziridines in (−)-(**R**)- *and* (+)-(S)-2,2,2-*Trifluoro*-1-*phenylethanol*.—The nitrone (20—100 mg) was dissolved in a mixture of optically active alcohol (0.25 cm^3) and fluorotrichloromethane (0.25 cm^3) in a stoppered Pyrex n.m.r. tube and placed in a Pyrex Dewar flask or a low-temperature photolysis cell maintained at the recorded temperature by a circulated coolant (MeOH, +25 to −40 °C) or by solid carbon dioxide (−78 °C). The n.m.r. tube was exposed to u.v. light (>300 nm) provided by either a medium-pressure Hanovia UVS 500 or a Hanau TQ 150 mercury-vapour lamp. The product oxaziridine was isolated by preparative t.l.c. on silica gel using CH_2Cl_2 as eluant since the differences in R_F values of the nitrone (<0.1), oxaziridine (0.5—0.6) and chiral alcohol solvent (0.2—0.3) were sufficiently large to permit a total separation and recovery. The oxaziridine was found to be free from impurities by t.l.c. and n.m.r. analysis, and by the observation of total racemization of the product oxaziridines (**2d**) and (**2e**) by heating in C_2Cl_4 solution at temperatures of 55 °C and 120 °C in accord with earlier results.[8]

General Procedure for the Photoracemization and Photoepimerization of Optically Active Oxaziridines.—The oxaziridine was placed in either a quartz n.m.r. tube (*ca.* 0.1 g in $CDCl_3$) or a quartz cell fitted with an internal water-cooled finger (0.02M in $CHCl_3$) and irradiated by u.v. light (254 nm) produced by either a Hanovia (Reading Reactor) low-pressure mercury-vapour lamp or a series of circular low-pressure mercury lamps available from Ultraviolet Instruments Inc. (model PCQ-X1). The reaction vessel and contents were maintained at a temperature of *ca.* 25 °C throughout the period of irradiation by using the water cooling system and a circulating fan. The reaction progress was monitored by n.m.r. spectroscopy. The nitrone and oxaziridine products were separated by column chromatography on silica gel using dichloromethane or light petroleum–ether (95:5) as eluant.

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