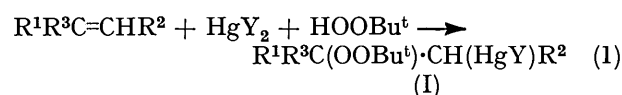


Oxymetallation. Part IX.¹ Bromodemercuration of Peroxymercurials derived from Terminal, Medial, and Cyclic Alkenes to give β -Bromo-peroxides

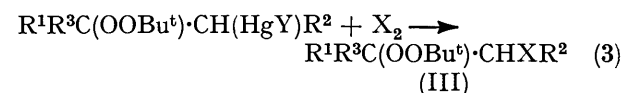
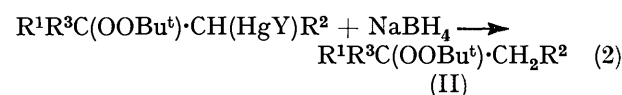
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Each of the peroxymercurials $R^1R^3C(OOBu^t)\cdot CH(HgBr)R^2$ derived from ethylene, propene, 2-methylpropene, but-2-ene, hex-3-ene, stilbene, prop-1-enylbenzene, cyclohexene, and norborn-2-ene reacts with bromine in dichloromethane to afford the corresponding β -bromo-peroxide $R^1R^3C(OOBu^t)\cdot CHBrR^2$, in ca. 85% yield; the new compounds have been characterised by 1H n.m.r. spectroscopy. The bromo-peroxides derived from non-terminal alkenes are obtained as 1 : 1 mixtures of diastereoisomers except for the norbornene derivative where the ratio of isomers is 65 : 35. The extent of racemisation is considerably reduced by carrying out the bromodemercuration in pyridine; isomer ratios of 4 : 1 are thus readily obtained.

PEROXYMERCURATION [equation (1)] has provided the basis for the synthesis of many new functionally substituted organic peroxides. Thus β -mercurated peroxides (I) have been prepared from mono-, 1,1-di-, and 1,2-di-alkylated (or arylated) ethylenes,²⁻⁵ vinyl ether and acetate,⁶ $\alpha\beta$ -unsaturated ketones and esters,⁷ and $\alpha\beta$ -unsaturated aldehydes and peroxyacetals.⁸



These compounds (I) have in turn proved valuable starting materials for the synthesis of functionally substituted peroxides which do not contain mercury. Hydridodemercuration [equation (2)] of derivatives from $\alpha\beta$ -unsaturated ketones and esters has afforded β -methoxycarbonyl-substituted peroxides (II; $R^2 = CO_2Me$) and α -carbonyl peroxides (II; $R^2 = H$, $R^1 = Me$, $R^3 = COMe$ or CO_2Me),⁹ and halogenodemercuration [equation (3)] of these derivatives has yielded organic peroxides containing both carbonyl and halogeno-substituents (III; $R^3 = H$, $R^2 = CO_2Me$ or $COPh$, $X = Cl$, Br , or I ; $R^2 = H$, $R^1 = Me$, $R^3 = COMe$ or CO_2Me , $X = Br$ or I).¹⁰



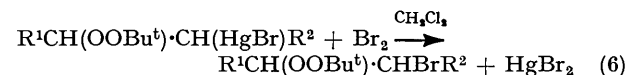
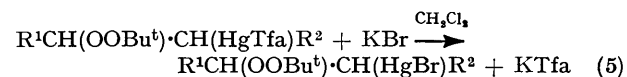
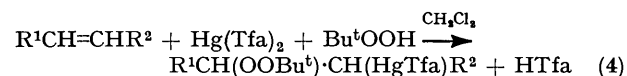
Surprisingly, the corresponding conversion of simple alkenes into β -halogeno-peroxides has received only scanty attention.^{2,3} One reason for this is that until recently peroxymercurations were carried out with mercury(II) acetate [equation (1; $Y = OAc$)] and whereas this affords clean products from $\alpha\beta$ -unsaturated

carbonyl compounds, those from simple alkenes are contaminated with β -mercurated acetates, $R^1R^3C(OAc)\cdot CH(HgOAc)R^2$.

The discovery⁵ that this complication is avoided by using mercury(II) trifluoroacetate [equation (1; $Y = O_2C\cdot CF_3$)] has opened the way for easier and more efficient peroxide syntheses. Consequently we have combined peroxymercuriation of simple alkenes using mercury(II) trifluoroacetate with bromodemercuration to prepare β -bromo-peroxides. Five such substances have been described before,² but only one of these was substantiated by elemental analysis and in all examples the halogen was attached to a primary carbon atom (III; $R^2 = H$). By extending the reaction to simple medial alkenes [equation (3; $R^3 = H$)], where diastereoisomeric bromo-peroxides can result, we have been able to observe the stereochemistry of bromodemercuration and to compare it with the unusual results previously found¹⁰ for the corresponding methyl cinnamate derivatives.

RESULTS

Reaction Conditions and Product Characteristics.—Table 1 lists the β -bromo-peroxides prepared by the sequence of reactions summarised in equations (4)–(6) ($Tfa = O_2C\cdot CF_3$). By carrying out the bromolysis on the organo-



mercury bromides rather than the trifluoroacetates the possible complication of anion exchange preceding demercuration, as found in a related system [equation (7)],¹⁰

⁶ E. Schmitz and O. Brede, *J. prakt. Chem.*, 1970, **312**, 43.

⁷ A. J. Bloodworth and R. J. Bunce, *J. Chem. Soc. (C)*, 1971, 1453.

⁸ A. J. Bloodworth and R. J. Bunce, *J. Organometallic Chem.*, 1973, **60**, 11.

⁹ A. J. Bloodworth and R. J. Bunce, *J.C.S. Perkin I*, 1972, 2787.

¹⁰ A. J. Bloodworth and I. M. Griffin, *J.C.S. Perkin I*, 1974, 688.

¹ Part VIII, A. J. Bloodworth and I. M. Griffin, *J.C.S. Perkin II*, 1975, 531.

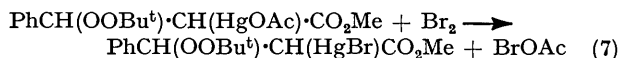
² E. Schmitz, A. Rieche, and O. Brede, *J. prakt. Chem.*, 1970, **312**, 30.

³ D. H. Ballard and A. J. Bloodworth, *J. Chem. Soc. (C)*, 1971, 945.

⁴ A. J. Bloodworth and G. S. Bylina, *J.C.S. Perkin I*, 1972, 2433.

⁵ A. J. Bloodworth and I. M. Griffin, *J.C.S. Perkin I*, 1975, 195.

was avoided. Full details of the first two steps have been reported⁵ and the yields listed in Table 1 are for the




final stage in isolation. Since the peroxymercuration proceeds in *ca.* 85% yield, the overall yield of bromo-peroxide from alkene is *ca.* 70–75%.

B.p.s were determined for three of the new compounds (Table 1) and all of them were characterised by ¹H n.m.r. spectroscopy (Table 2). Spectroscopic assignments were based mainly on comparison with the parent organomercury bromides.⁵

diastereoisomeric pairs on enantiomers can exist in each case. The peroxymercurials obtained were all single diastereoisomers⁵ but upon brominolysis in dichloromethane they each gave nearly equal amounts of *both* diastereoisomers of the corresponding bromo-peroxide, except for the norbornene derivative where the ratio of isomers obtained was 65 : 35.

Stereoselectivity was achieved carrying out the reaction in more polar solvents. In methanol the ratio of diastereoisomeric bromo-peroxides from the *cis*-but-2-ene peroxymercurial was 1 : 2, but *ca.* 25% of the product was a methoxy-containing compound (*cf.* ref. 10). Greater stereoselectivity, without the complication of solvolytic

TABLE 1
β-Bromo-peroxides *

Parent alkene	R ¹	R ²	Yield (%)		Found (%)		Calc. (%)		B.p. (°C) [mmHg]
			Crude	Pure	C	H	C	H	
Ethylene	H	H	<i>a</i>	80	36.1	6.5	36.6	6.65	
Propene	Me	H	<i>a</i>	81 ^b	40.3	7.0	39.8	7.2	
<i>cis</i> -But-2-ene ^c	Me	Me	83	64 ^d	42.4	7.5	42.7	7.6	44–46 [3.2]
<i>trans</i> -Hex-3-ene	Et	Et	87	<i>d</i>	46.8	8.15	47.4	8.4	42 [0.55]
<i>cis</i> -Stilbene ^c	Ph	Ph	<i>a</i>	79	62.2	5.8	61.9	6.1	
<i>trans</i> -Prop-1-enylbenzene	Ph	Me	65	<i>d</i>	53.1	6.3	54.4	6.7	
Cyclohexene	[CH ₂] ₄		87	<i>d</i>	47.3	7.45	47.8	7.6	48 [0.25]
Norborn-2-ene			<i>a</i>	87	51.0	7.35	50.2	7.3	


* The bromo-peroxides derived from medial alkenes were mixtures of diastereoisomers.

^a Product required no further purification. ^b Found: Br, 37.8. C₇H₁₅BrO₂ requires Br, 37.9%. ^c The same mixture of diastereoisomers was obtained from the mercurial derived from the *trans*-alkene. ^d Purified by distillation.

In addition, the compound Me₂C(OOBu^t)·CH₂Br (78%) was prepared from 2-methylpropene (Found: C, 42.9; H, 7.6. C₈H₁₇BrO₂ requires C, 42.7; H, 7.6%).

TABLE 2

¹H N.m.r. spectra (τ values; 60 MHz) of β-bromoperoxides R¹CH_A(OOBu^t)·CH_BBrR² in carbon tetrachloride

Parent alkene	R ¹	R ²	Concn. (% w/v)	τ					J/Hz ^a		
				H _A	H _B	R ¹	R ²	Bu ^t	R ¹ H _A	H _A H _B	H _B R ²
Ethylene	H	H	32	5.82 ^b	6.48 ^b	5.82 ^b	6.48 ^b	8.77			
Propene	Me	H	23	5.82dqin	6.40dd	8.72d	6.65dd ^c	8.77	4.0	4.0	10.3
<i>cis</i> -But-2-ene ^d	Me	Me	28 ^e		5.3–5.9m	8.80d	8.40d	8.77	6.9		6.4
<i>trans</i> -But-2-ene ^d	Me	Me	30 ^f	6.13dq	5.59dq	8.77d	8.34d	8.77	6.3	4.7	7.0
<i>trans</i> -Hex-3-ene	Et	Et	34 ^g		5.5–6.4m		7.9–8.5m ^h	8.76			
							8.85–9.1m ⁱ				
<i>cis</i> - or <i>trans</i> -Stilbene	Ph	Ph	28 ^g		4.75d ^j			8.74		7.3	
					4.87d ^j		2.73s, 2.84s				
					4.79s			8.89			
<i>trans</i> -Prop-1-enylbenzene	Ph	Me	19 ^g	5.02d	5.3–	2.65s	8.33d	8.77	5.7		7.2
				5.03d	5.8m		8.50d	8.79	4.8		6.7
Cyclohexene	[CH ₂] ₄		37 ^g		5.2–6.4m		7.7–8.6m	8.76			
Norborn-2-ene			49 ^g		6.0–6.15m		7.4–7.7m ^k	8.75			
							8.1–8.7m ^l	8.78			

^a By first-order analysis. ^b A₂B₂m; similar to that reported for D₂N·CH₂·CH₂·CO₂D (R. M. Silverstein and G. C. Bassler, 'Spectrometric Identification of Organic Compounds,' 2nd edn., Wiley, New York, 1967, p. 126). ^c J(H_AR²) 7.5 Hz. ^d From reaction in pyridine. ^e Contained 6% of other diastereoisomer. ^f Contained 19% of other diastereoisomer. ^g Of the mixture of diastereoisomers. ^h CH₂·CH₃. ⁱ CH₂·CH₃. ^j Calculated by analysis of the AB system. ^k Of bridgehead protons. ^l Of methylene protons.

In contrast to the clean reactions in Table 1, the bromodemercuration of 2-bromomercurio-1-phenylethyl *t*-butyl peroxide (from styrene) gave *ca.* 11% of phenacyl bromide in addition to the expected bromo-peroxide; this agrees with an earlier observation for the same reaction in carbon tetrachloride or glacial acetic acid.³ A mixture of 2-bromo-1-phenylethyl *t*-butyl peroxide and bromine gave phenacyl bromide when exposed to sunlight.

Influence of Solvent on Stereochemistry.—The peroxymercurials and related bromo-peroxides from medial alkenes contain two asymmetric carbon atoms, so that two

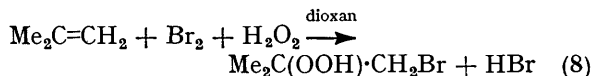
decomposition, was obtained for the but-2-ene derivatives in pyridine. The reaction temperature was varied, and an attempt was made to eliminate any photo-induced free-radical brominolysis in some reactions by carrying them out in a black flask. The results [reported as follows: *cis*- or *trans*-but-2-ene derivative, clear or black flask, temperature, reaction time, yield (crude), ratio of diastereoisomeric β-bromo-peroxides (isomer with downfield Me-CHBr doublet in n.m.r. quoted first)] were: (i) *cis*, clear, 24°, 25 min, 54%, 15 : 85; (ii) *cis*, clear (but ice packed around flask), 0°, 1 h, 62%, 20 : 80; (iii) *cis*, clear, –35°,

6.5 h, 61%, 35:65; (iv) *cis*, black, 24°, 1.5 h, 52%, 5:95; (v) *cis*, black, -35°, 8 h, 38%, 20:80; (vi) *trans*, clear (but ice packed around flask), 0°, 4 h, 52%, 80:20; (vii) *trans*, black, 24°, 1.5 h, 43%, 75:25.

DISCUSSION

The results show that the sequence of peroxymercuration and bromodemercuration is a very attractive route to β -bromo-peroxides. Both stages are easy to carry out, proceed under mild conditions, and rapidly give high yields of products which require little purification. Above all the method is versatile, being applicable to terminal, medial, and cyclic alkenes from which products which are secondary or tertiary peroxides, and primary or secondary alkyl bromides can be obtained.

In fact no other route to these compounds has been reported. The simplest alternative which can be envisaged involves treating alkenes directly with *t*-butyl hydroperoxide and bromine. The corresponding reaction with hydrogen peroxide [*e.g.* equation (8)] has previously afforded β -bromo-hydroperoxides in yields



of up to 54%.¹¹ However a preliminary attempt to prepare 1-bromo-2-*t*-butylperoxycyclohexane under similar conditions failed, the main product being 1,2-dibromocyclohexane.¹²

The only drawback of the peroxymercuration route is that the β -bromo-peroxides from medial alkenes are obtained as mixtures of diastereoisomers. Isomer ratios of about 4:1 are readily obtained by carrying out the bromodemercuration in pyridine, but mechanical problems in extracting the bromo-peroxides result in yields being then reduced to *ca.* 50%.

The stereochemistry of these bromodemercurations is broadly in line with that of the halogenolysis of other organomercurials for which racemisation occurs in non-polar solvents and retention in pyridine.¹³ We previously identified the configurations of the peroxymercurials on the basis of vicinal proton-proton coupling constants.¹ However it proved impossible to make similar assignments with the bromo-peroxides so that we are unable to confirm that the stereoselectivity found in pyridine results from predominant retention.

The present results underline the unusual nature of the bromodemercuration of methyl cinnamate peroxymercurials, $\text{PhCH}(\text{OOBu}^t)\cdot\text{CH}(\text{HgBr})\cdot\text{CO}_2\text{Me}$, for which stereoselectivity in dichloromethane and complete racemisation in pyridine were observed.¹⁰ They support the view¹⁰ that the α -methoxycarbonyl group

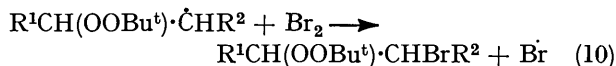
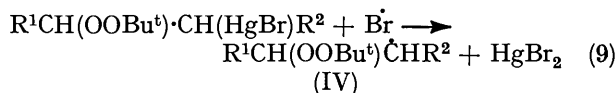
¹¹ M. Schulz, A. Rieche, and K. Kirschke, *Chem. Ber.*, 1967, **100**, 370.

¹² A. G. Davies, personal communication.

¹³ (a) M. H. Abraham, 'Comprehensive Chemical Kinetics,' ed. C. H. Bamford and C. F. H. Tipper, Elsevier, Amsterdam, 1973, vol. 12; (b) F. R. Jensen and B. Rickborn, 'Electrophilic Substitution of Organomercurials,' McGraw-Hill, New York, 1968; (c) O. A. Reutov and I. P. Beletskaya, 'Reaction Mechanisms of Organometallic Compounds,' North-Holland, Amsterdam, 1968.

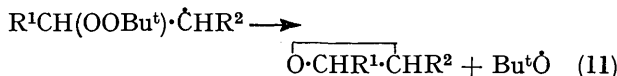
rather than the β -peroxy-group is responsible for the anomalous behaviour.

By analogy with other organomercurials¹³ the racemisation in dichloromethane probably indicates a free-radical chain mechanism for the brominolysis, with the propagation stage shown in equations (9) and (10).



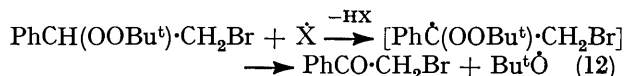
The non-equal isomer distribution from the norbornene derivative is not inconsistent with this, for the stereochemistry of chain transfer to a norborn-2-yl radical bearing an *exo*-3-substituent can vary from complete *exo*-attack to total *endo*-attack, depending upon the nature of the substituent.¹⁴ We are unable to identify the predominant mode of attack on the *exo*-3-*t*-butylperoxynorborn-2-yl radical because the complexity of the ¹H n.m.r. spectrum in the 2-H,3-H region prevented assignment of configurations to the individual diastereoisomers.

This mechanism requires that bromodemercuration in dichloromethane proceeds through the same intermediate β -peroxyalkyl radicals (IV) as involved in hydridodemercuration.⁴ In the latter reaction, ring closure of these radicals [equation (11)] competes with their reduction, but no epoxides were detected in the products of brominolysis. This is not surprising since



the initial bromine concentration is about 0.3 mol l⁻¹ and abstraction of bromine by an alkyl radical is expected to be very fast,¹⁵ probably diffusion-controlled and therefore with a rate coefficient about a thousand-fold greater than that for the most favoured closure.¹⁶

The formation of phenacyl bromide can also be explained by a homolytic process if radical attack on 2-bromo-1-phenylethyl *t*-butyl peroxide [equation (12)] competes with attack on the parent peroxymercurial [equation (9)] as the concentration of the latter falls



off. Such a reaction should be favoured for this particular peroxide since the hydrogen abstracted is benzylic. The absence of acyl bromide formation in the stilbene system, where a similar benzylic hydrogen is present, may be attributed to the fact that the competing S_H2 process at mercury [equation (9); R¹ = R² = Ph] also generates a benzylic radical whereas

¹⁴ D. I. Davies in 'Essays in Free Radical Chemistry,' *Chem. Soc. Special Publ.* No. 24, 1970, p. 204.

¹⁵ L. Batt and F. R. Cruickshank, *J. Phys. Chem.*, 1967, **71**, 1836.

¹⁶ A. J. Bloodworth, A. G. Davies, I. M. Griffin, B. Muggleton, and B. P. Roberts, *J. Amer. Chem. Soc.*, 1974, **96**, 7599.

in the styrene peroxymercurial only a primary radical is formed.

EXPERIMENTAL

The β -peroxyalkylmercury bromides were prepared as previously described.⁵ Commercial bromine (AnalaR), dichloromethane (reagent grade), light petroleum (b.p. 40–60°; reagent grade), and pyridine (AnalaR) were used without further purification.

¹H N.m.r. spectra (60 MHz) were recorded on a Perkin-Elmer R12 instrument; the spectrum of 2-bromo-3-t-butylperoxynorbornane was also recorded on a spectrometer operating at 100 MHz (Varian HA-100) for determination of the ratio of diastereoisomers.

Bromodemercuration.—The reactions were usually carried out in subdued lighting. The following general procedure was adopted although the quantities used varied from a quarter to double those given here.

Bromine (11 mmol) in dichloromethane (10 ml) was added, dropwise at first, to a stirred solution of the β -peroxyalkylmercury bromide (10 mmol) in dichloromethane (20 ml). The mixture was stirred for 5.5 h then left overnight. The insoluble mercury(II) bromide was filtered off and the solvent removed from the filtrate at 12 mmHg. The residue was extracted with light petroleum (1 × 8 plus 2 × 4 ml) and the light petroleum removed at 12 mmHg for 2 h to give the bromo-peroxide (ca. 85%) as an oil.

Five bromo-peroxides were obtained analytically pure at this stage. Four others showed no proton-containing impurities (¹H n.m.r. spectra) but had carbon analyses

low by 1–2%, presumably owing to the presence of mercuric bromide; three of these were purified by distillation. The preparation of the *trans*-prop-1-enylbenzene product was carried out on a 2.5 mmol scale and further purification was not attempted. Yields, b.p.s, and analyses are given in Table 1 and ¹H n.m.r. spectral data are recorded in Table 2. The mass spectrum of the product from *cis*-but-2-ene (inlet temperature 55°) showed parent ions at *m/e* 224 (⁷⁹Br) and 226 (⁸¹Br) and intense peaks at *m/e* 135 and 137 (*M* – 89). Similar spectra have been reported for 2-phenyl-2-t-butylperoxyethyl bromide and iodide³ and for β -halogeno-peroxides derived from $\alpha\beta$ -unsaturated carbonyl compounds.¹⁰

A similar procedure was followed for bromodemercurations in pyridine.

Ratios of diastereoisomers were determined from the ¹H n.m.r. spectra of the bromo-peroxides by integration of the *MeCHBr* doublets for the but-2-ene and *trans*-prop-1-enylbenzene derivatives and the *Bu^t* singlets for the stilbene, *trans*-hex-3-ene, and norbornene derivatives; the figures are rounded to the nearest 5%.

Errata.—The ¹H n.m.r. data for β -carbonyl- β -halogeno-peroxides reported in ref. 10 contain some errors. In Table 3 the following changes should be made in the chemical shifts of H _{α} : compd. 2, 5.64 for 5.74; compd. 4, 4.68 for 4.93; compd. 5, 4.55 for 4.81; and of H _{β} : compd. 4, 4.46 for 4.23; compd. 5, 4.31 for 4.07.

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