TABLE I

Autoxidation of Methyl Oleate in Emulsion, Prepared with Sodium Dodecylsulfate, at 30C

Histidine M	Fe^{+++} M	Mmole O_2/mole methyl oleate 22 hr
0	0	1.3
0.01	0	8.0
0	2×10^{-4}	42.0
0.01	2×10^{-4}	104.0[a]
0	2×10^{-5}	4.4
0.01	2×10^{-5}	61.0

[a] Calculated value based upon the rate of oxygen absorption at the thirteenth hour of oxidation.

the interface complexed by the ferric ion.

The catalysts and reactive groups are thus present at the interface in high concn and oriented in positions which should be highly favorable to energy transfer. This is in accord with experience where a rapid rate of autoxidation is obtained. The myristate and palmitate soaps would be expected to behave quantitatively alike since each would have a carboxyl group oriented at the boundary and exerting the same electrostatic force. The sulfate group of sodium dodecylsulfate would exert a force which was similar in type of effect but different in amount.

From a consideration of the nature of the interface, we would expect that increasing the concn of the emulsifier, sodium dodecylsulfate beyond an optimum amount (0.002 M) or by adding sodium salts such as sodium chloride, would increase the concn of sulfate and sodium ions at the boundary. It is suggested that these would act as a barrier hindering contact between the catalyst and reacting groups in the autoxidation. This would explain the retarding effects of increased emulsifier or salt concn. In case of the sodium phosphates, part of the suppressing effect can be attributed to the increase in concn of the sodium ions at the boundary as with other salts. However, since the suppression of catalysis is so complete, it is believed that the phosphate ion also interacts with the catalyst rendering it inactive (7).

When we employed a nonionic emulsifier such as the polyoxyethylene ether of tetradecanol, the rate of the histidine-catalyzed reaction differed only slightly from the uncatalyzed rate. This would be expected for in this emulsion, there is no ionized charge at the interface. As a result metal ions and histidine will be distributed randomly throughout the bulk aqueous phase and the chance of a metal-complex catalyzed reaction at the interface would be slight. The fact that histidine becomes mildy pro-oxidative only when some oxidation has taken place may be explained by an alternative mechanism proposed by Ingold (3) in the discussion of metal catalysis of lipids in emulsion. It was suggested that since hydrated metal ions (catalyst) are present only in the water phase, they may exert their effect in this phase by reacting with water-soluble radicals (e.g., ·OH, ·OOH) or oxidation products (e.g., hydroperoxide) which would be more soluble in water than the original substrate. This is in accord with our observation that histidine has a pro-oxidative action in nonionic emulsions only when oxidation products are present.

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The Elaidinization of Methyl Oleate with Mercaptans[1,2]

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Abstract

Methyl oleate is transformed into methyl elaidate by mercaptans. The equilibrium mixture, containing 77% elaidate, can be obtained from either isomer. A concomitant, although much slower reaction, is the addition of the sulfhydryl group to the double bond of either ester. The effects of numerous reaction conditions on the extent and rate of the isomerization are given. The reaction is presented as an incipient addition of the mercaptan to the double bond, as a reversible thiyl radical attack on one of the unsaturated carbon atoms.

Introduction

DURING RATE STUDIES on the addition of methyl mercaptan and β-mercaptopropionic acid to methyl sterculate and sterculene in dilute solutions, methyl oleate was used as a blank to check the reactivity of a common unsaturated ester to sulfhydryl addition (6). Very little addition of the mercaptans to methyl oleate was observed; a routine check, however, of the IR spectrum of the products from a blank run showed a new band in the methyl oleate spectrum at 10.33 μ indicative of the *trans* double bond (12,13). Since the elaidinization of oleic acid or oleates is usually carried out with selenium or sulfur at high temp (3,8,9,16) or with oxides of nitrogen at lower temp (4,5,10,11), the sulfhydryl catalyzed isomerization in dilute solution seemed sufficiently novel to warrant its investigation. The reaction was also of interest because of its biological implications; the proteins involved in lipid transport and metabolism often contain sulfhydryl groups (1).

Experimental

Materials. Technical grade methyl oleate (518 g) was distilled to yield only the C_{18} esters. These were saponified and the acids crystallized from ethanol (2 liters) at 10C, 0C and −15C. Each fraction was recrystallized from petroleum ether (Skellysolve B) at −15C to yield oleic acid. After esterification with freshly prepared 7% BF_3 in methanol (2 liters) at room temperature for 24 hr, the product was distilled to yield 250 g methyl oleate bp 140°/0.4 mm, n_D^{30} 1.4487 [lit. 1.4484 (13)].

Elaidic acid, mp 44–6C [lit. 44 (13)], obtained from an isomerization run was similarly converted to the

[1] Presented at the AOCS meeting in Minneapolis, 1963.
[2] Contribution No. 858 of the Agricultural Experiment Station, University of Arizona.

TABLE I

Effect of Mercaptan Structure on the Isomerization

Mercaptan	% Elaidate	
	5 hr	24 hr
β-Mercaptopropionic acid	61	64
Glycol dimercaptoacetate	64	54
Thiomalic acid	75	79
1,4-Butanedithiol	63	64
1,5-Pentanedithiol	58	59
Benzylmercaptan	22	39
α,α'-Dimercapto-p-xylene	19	30
1,10-Decanedithiol	33	29
Ethylcyclohexyl dimercaptan	6	27
Methyl mercaptan	4	12
Ethyl mercaptan	5	10
Cysteine hydrochloride	0	1
Methyl cysteinate hydrochloride	4	3
None (methyl oleate blank)	−3	0
None (methyl elaidate blank)	97	100

methyl ester, bp 125–6C/0.125 mm, n_D^{30} 1.4473 [lit. 1.4492 (13)]. Both esters gave a single symmetrical peak on GLC.

Methyl linoleate and linolenate were purchased from The Hormel Foundation; olive oil from a local store.

The mercaptans were used as received from Eastman, Aldrich, Phillips or Evans Chemetics, Inc.; reagent-grade solvents were used without further purification.

Analytical. The initial concn of esters in the reaction mixtures were determined by dilution of weighed quantities. The mercaptan concn were determined before and during the reactions by titration of aliquots with 0.1 N I_2 in 95% ethanol. For this titration, water must be added to the solution to be titrated to assure a sharp endpoint.

The percentage of *trans* component in the methyl ester mixture isolated from the reactions was determined by IR spectroscopy (12) in CS_2 solution in 0.5-mm cells with a Perkin-Elmer Infracord 137B spectrophotometer. A standard curve was prepared from known mixtures of methyl oleate and elaidate relating optical density at 10.33 μ and ester concn to the amount of methyl elaidate in the mixture.

Rate Runs. The reactions were initiated by mixing the ester and β-mercaptopropionic acid solutions at zero time in polyethylene stoppered 50 or 125-ml Erlenmeyer flasks. In all of the runs comparative experiments were done concurrently. The same stock solutions or solvents were used because the rates observed were a function of the prior history of the solutions.

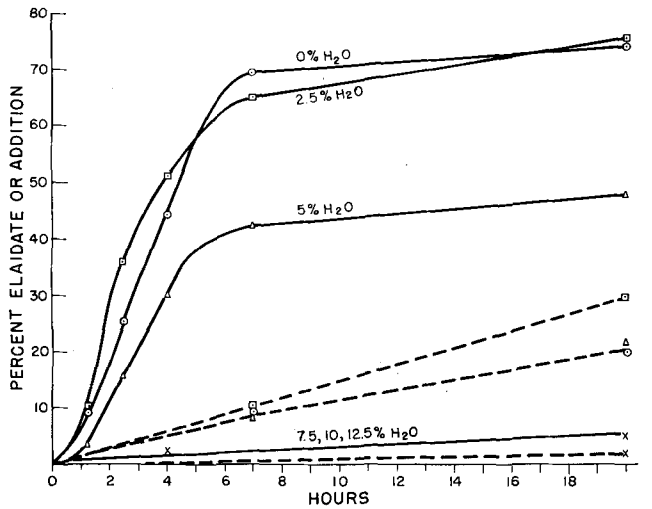


FIG. 1. Effect of water on the isomerization and addition reactions in ethanol.

Solid lines: per cent elaidate. Dashed lines: per cent addition.

TABLE II

Effect of Solvent on the Isomerization

Solvent	% Elaidate		
	β SH	α,α'	MeSH
95% Ethanol	76	29	7
Methanol	32	17	4
Tetrahydrofuran	39	7	10
Ether	22	2	2
Carbon tetrachloride	28	2	7
Benzene	9	2	0
Pyridine	0	0	3
Piperidine	5[a]	0[b]	10[a]
Skellysolve B	0	0	1
Chloroform	5	2	1

[a] 70–80% of the mercaptan was consumed in these reaction mixtures.
[b] Precipitation of the mercaptan piperidinium salt occurred.

Samples (5 or 10 ml) of the reaction mixtures were removed periodically, added to 15 ml water and their sulfhydryl contents determined iodometrically. Excess iodine was destroyed with a little thiosulfate solution, 30 ml of 0.5 N sodium hydroxide was added and the mixtures were extracted with low boiling petroleum ether (Skellysolve F, 8 ml) in the titration flasks. Portions of the supernatant solutions were evaporated, first on a steam bath and then at 50–70C at 0.1 mm and the residual mixture of methyl oleate and elaidate analyzed spectrophotometrically as outlined above.

The lower, alkaline, aqueous phases containing the iodine oxidized β-mercaptopropionic acid as its sodium salt:

$$(^-S-CH_2-CH_2-COO^-Na^+)_2$$

as well as the sodium salts of the two addition products:

$$CH_3-(CH_2)_x-\underset{\displaystyle S}{\underset{|}{CH}}-(CH_2)_y-COOCH_3 \qquad x = 7,\ y = 8$$

$$\text{or}$$

$$CH_2-CH_2-COO^-Na^+ \qquad x = 8,\ y = 7$$

were discarded.

The amounts of methyl elaidate shown in the tables and figures are expressed as the percentage of elaidate in the oleate-elaidate mixtures isolated from the reactions, not as a percentage of the methyl oleate or elaidate originally placed in the reaction mixtures.

When methyl oleate and elaidate were run through the titration-extraction-analysis procedures, they analyzed for −3 to 0% and 97–103% methyl elaidate, respectively, showing that no isomerization occurs during the analysis.

Unless otherwise noted, all runs were made on the desk top in diffuse light at room temp (26–28C) in 95% ethanol.

Results

Effect of Mercaptan Structure. Solutions 0.2 M in methyl oleate and 0.2 N in mercaptan were analyzed for elaidate after 5 and after 24 hr. The data show in Table I.

Effect of Solvent. A. Approximately 0.2 N solutions of β-mercaptopropionic acid (β-HS),α,α'-dimer-

TABLE III

Effect of Oleate and Mercaptan Concentrations on the Rate of Isomerization

[β SH] M	[Oleate] M	% Elaidate		
		After 2¼ hr	After 5 hr	After 8½ hr
0.2	0.2	61	75	77
0.2	0.1	57	69	69
0.2	0.05	68	70	72
0.1	0.2	25	52	64
0.1	0.1	29	44	59
0.1	0.05	17	33	48
0.05	0.2	3	6	12
0.05	0.1	3	10	18
0.05	0.05	3	9	13

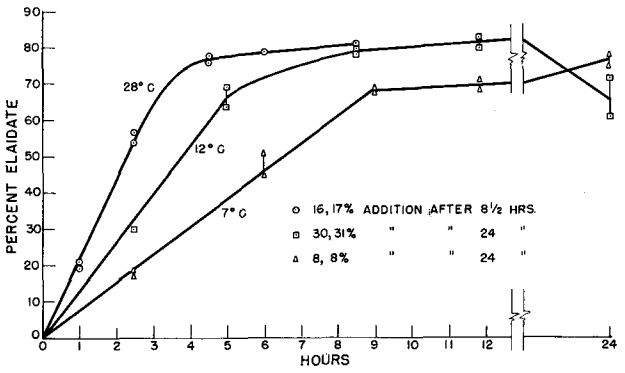


FIG. 2. Effect of temp on the rates of isomerization and addition.

capto-p-xylene (α,α'), and methyl mercaptan (MeSH) were prepared in 10 solvents. Thirty ml each solution was added to 1.8 g methyl oleate; the elaidate content of each solution was measured after 25 hr in the β-HS and α,α', experiments and after 43 hr in the MeSH experiment. The data show in Table II.

Effect of Solvent. B. Solutions were prepared from methyl oleate, β-mercaptopropionic acid, absolute ethanol and water to contain 0.2 M reactants and 0–12.5% water. Samples were removed periodically for analysis; the results show in Figure 1.

Effect of Reagent Concentrations. Aliquots of freshly prepared 0.4 M solutions of methyl oleate and β-mercaptopropionic acid were mixed with 95% ethanol to give reaction mixtures 0.2, 0.1 and 0.05 M in each reagent in all combinations. Samples were removed, washed with aqueous alkali and analyzed for elaidate. The results show in Table III.

Effect of Temperature. Duplicate solutions containing methyl oleate and β-mercaptopropionic acid (0.2 M each) were placed in a freezer (−22C), a refrigerator (6C), a water bath (12C) and the desk top (26C). Samples were removed periodically and analyzed for elaidate; at the end of the run aliquots were titrated for sulfhydryl consumption. After 9.5 hr the mixtures held at −22C contained only 1–2% elaidate; they were discarded. The results from the other runs show in Figure 2.

Effect of Sunlight. Solutions containing methyl oleate and β-mercaptopropionic acid (0.1 M each) were placed in direct sunlight or in diffuse light. In another experiment the solutions were 0.2 M in oleate and 0.1 M in β-mercaptopropionic acid. The data show in Figure 3.

The Oleate ⟷ Elaidate Equilibrium and the Effect of an Inert Atmosphere on the Rate of Isomerization. Four solutions were prepared, all 0.2 M in β-mercaptopropionic acid. The first two were 0.2 M in methyl oleate, the third 0.2 M in methyl elaidate and the fourth 0.15 M in elaidate and 0.05 M in oleate. The reactant solutions for one of the 0.2 M oleate runs were thoroughly flushed with nitrogen before mixing and the reaction mixture subsequently kept under a nitrogen atmosphere. Aliquots from the four solutions were withdrawn periodically for analysis. The data are presented in Figure 4.

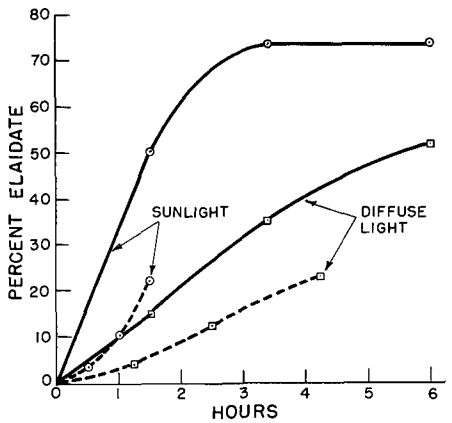


FIG. 3. Effect of sunlight on the isomerization rate.
Solid lines: 0.1 M reagents. Dashed lines: 0.2 M oleate, 0.1 M β-mercaptopropionic acid.

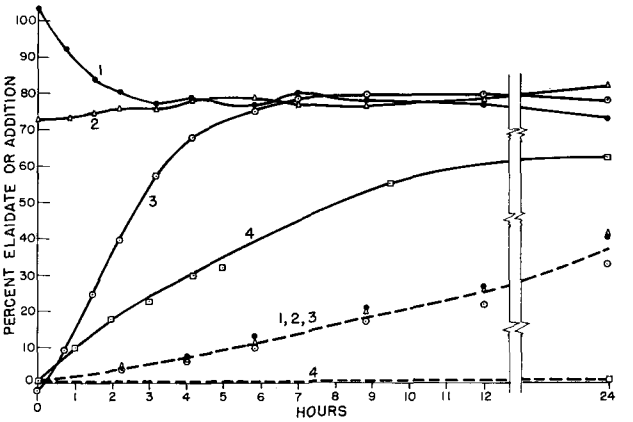


FIG. 4. Determination of the oleate-elaidate equilibrium and effect of an inert atmosphere on the isomerization rate and amount of addition.
Solid lines: per cent elaidate. Dashed lines: per cent addition. Curves: 1—methyl elaidate, 2—3:1 elaidate:oleate, 3—methyl oleate; 4—methyl oleate under N_2.

The sulfhydryl consumption of the three reaction mixtures under air rose evenly to 26% after 12 hr and 40% after 24 hr. There was no sulfhydryl consumption in the reaction mixture held under nitrogen; after 24 hr the iodine titer of an aliquot was the same as it was at zero time (21.0 vs. 21.0 ml).

Experiments with Methyl Linoleate, Linolenate and Olive Oil. Absolute ethanol solutions of methyl oleate (0.2 M), olive oil (0.2 M, assumed MW = 300/double bond), methyl linoleate (0.1 M) and methyl linolenate (0.067 M) were prepared. All solutions were also 0.2 M in β-mercaptopropionic acid. They were sampled as usual for analysis. The results show in Figure 5.

After 24 and 48 hr the isomerized olive oil isolated from the reaction mixture was a very viscous liquid; after 96 hr it was a waxy solid.

Discussion

From the tables and figures the following points are evident:

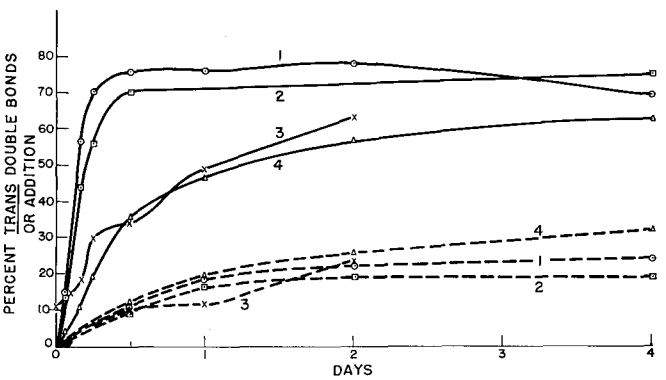


FIG. 5. Isomerization and addition reactions.
Solid lines: per cent of total double bonds in *trans* configuration. Dashed lines: per cent of original double bonds that have added mercaptan. Curves: 1—methyl oleate, 2—olive oil, 3—methyl linolenate, 4—methyl linoleate.

1) The mercaptan catalyzed isomerization of methyl oleate is a function of mercaptan structure (Table I), solvent (Table II, Fig. 1), temp (Fig. 2), the presence or absence of sunlight (Fig. 3) and of oxygen (Fig. 4), and the mercaptan concn (Table III). The methyl oleate concn was the only variable which had a relatively small influence on the rate of elaidinization (Table III).

2) The equilibrium mixture of oleate and elaidate contains 75–80% of the *trans* isomer. This equilibrium is readily attained from either isomer or is maintained by a preformed mixture of the two (Fig. 4).

3) The addition of the mercaptan to the double bond of either isomer is a side reaction whose rate is considerably slower than the isomerization. The addition can be suppressed by working in an inert atmosphere (Fig. 4).

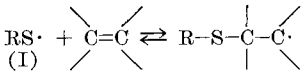
4) Even though 30–40% of the olefin has irreversibly added the sulfhydryl compound, the remaining portion maintains the equilibrium concn of oleate and elaidate (Fig. 1,4).

5) Like other *cis-trans* isomerizations, the mercaptan catalyzed reaction is not specific for methyl oleate, but also occurs with linoleate, linolenate and olive oil (Fig. 5).

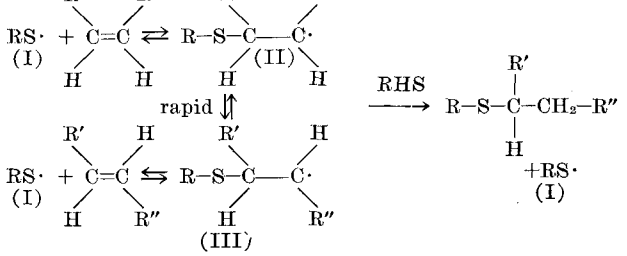
Similar studies have appeared in the literature. The methyl mercaptan catalyzed isomerizations of *cis* and *trans*-2-butene in the gas phase has been studied by Sivertz and co-workers (14,15) who showed that the isomerization is more rapid than the addition reaction and that *trans*-2-butene is converted to about a 3:1 *trans*:*cis* mixture. The same reaction in the liquid phase at 60C was described by Walling and Helmreich (17) who showed that the *cis* to *trans* isomerization was 85 times as rapid as the rate of sulfhydryl addition and that the *trans* to *cis* rate was 20 times as fast as the addition reaction.

Cunneen, Higgins and Watson (2) irradiated rubber and gutta-percha in the presence of thiolbenzoic acid or dibenzoyl disulfide at room temp or heated the mixtures to 140C in the absence of light. They reported that about 60% of the double bonds in the resulting polymers were in the *trans* form whether they started with the all *cis* rubber or the all *trans* gutta-percha. No mention was made of the addition reaction. Neureiter and Bordwell (7) showed that the addition of a few drops of thiolacetic acid to 1.7 g *cis*-2-chloro-2-butene followed by irradiation for an hr produced 80% of the *trans* isomer.

Sivertz (14) appears to have been the first to suggest the reversibility of the initial attack of the thiyl radical (I) on the unsaturated carbon atom:



This concept was elaborated by Walling (17) who postulated the following mechanism for the isomerization of the butenes (R, R′, R″ = CH_3).



A similar mechansm undoubtedly applies to the other studies noted above as well as the present work. The free radical attack and subsequent rotation about the carbon-carbon single bond followed by dissociation of the more favored *trans* intermediate (III, R′ = $CH_3(CH_2)_7$–, R″ = $-(CH_2)_7-COOCH_3$ or the reverse) to the *trans* isomer and the thiyl radical (I) is the most likely explanation for the mercaptan catalyzed isomerization of methyl oleate to elaidate.

This "incipient" addition of the mercaptan to form the intermediate radical mixture (II and III) requires an extra push to go over to full addition of the sulfhydryl group to the double bond. In the present study, this extra push is supplied by oxygen or free radical substances produced by oxygen. In the absence of air, the isomerization proceeded readily, albeit more slowly than in its presence, but full addition occurred very little or not at all.

The rates of the isomerization and addition reactions, viz: the formation of the thiyl radicals (I) or their addition to form the intermediates II and III, are quite dependent upon the solvent and the nature of R in RSH. The most active mercaptans appear to be those that are difunctional, with not too large a residue between the sulfhydryl group and the other functional groups. That the isomerizations did not proceed extensively in non-polar solvents may be explained in two ways. Either very few thiyl radicals formed in these solvents or the mercaptan was preferentially solvated by the ester function of methyl oleate and was inaccessible to the double bond.

It is possible that the equilibrium mixture of oleate and elaidate observed in this work with β-mercaptopropionic acid is not invariant and changes with different solvents or with the R in RSH, e.g., for certain R groups, the intermediate II may be the more favorable configuration or the rate of dissociation of II may be greater than that of III. In the light of the other work cited, however, with sulfur, selenium, oxides of nitrogen or other mercaptans as catalysts, and with the butenes, chlorobutenes, rubber and gutta-percha, the equilibrium composition of 70–80% *trans*, 30–20 *cis* double bonds seems to be universally held.

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