Chemical Consequences of the Intramolecular Interaction between a Sulphur Atom and a Methoxycarbonyl Group in Fluorene Systems[1]

Warō Nakanishi,* Yoshiaki Kusuyama, and Yoshitsugu Ikeda
Department of Chemistry, Faculty of Education, Wakayama University, Sakaedani, Wakayama 640, Japan
Michinori Ōki*
Department of Chemistry, Faculty of Science, The University of Tokyo, Bunkyo-ku, Tokyo 113, Japan

The intramolecular interaction between a sulphur atom and a methoxycarbonyl group was found to affect their chemical reactivity. The rates of C–S bond cleavage in methyl 9,9-bis(ethylthio)fluorene-*x*-carboxylate, where *x* is 1, 2, or 3, with sodium ethanethiolate show that the rate is minimal, though comparable with the others, when $x = 1$, because of steric effects. In contrast, methyl 9-(ethylthio)fluorene-*x*-carboxylates, where *x* is 1, 2, or 3, exhibit the maximum rate when $x = 1$. The rates of ester exchange in the presence of toluene-*p*-sulphonic acid indicate that the reaction is accelerated by the presence of two ethylthio groups at the 9-position of methyl fluorene-1-carboxylate but no significant effect is detected if there is only one ethylthio group. The hydrolysis of the thioketal group in 9,9-bis(ethylthio)fluorene is also accelerated by the presence of a 1-methoxycarbonyl group. The implications of these results are discussed with the use of a model compound.

Carbonyl compounds carrying an alkyl(or aryl)thio group at the α-position can be reduced by soft bases, including thiolate anions.[2] During the course of a study of the enhanced reactivity of these compounds towards soft bases, we encountered a C–S bond cleavage in the reaction of 9,9-bis(ethylthio)fluorene (**1**) with ethanethiolate in methanol to give 9-(ethylthio)fluorene (**5**) and diethyl disulphide. We have examined various sulphides which should give stable anions on cleavage of the C–S bond. As a result, it has become apparent that: (i) if there is no assistance of a carbonyl group, cleavage of the C–S bond requires a leaving group whose conjugate acid has a pK_a of less than 20; and (ii) the C–S bonds in α-alkyl(or aryl)thio carbonyl compounds react easily, irrespective of their rather high pK_as.[3] The cause of this facile C–S bond cleavage in these compounds is worth investigation.

If a sulphur atom and a carbonyl group are placed in proximity to each other, there should be a charge-transfer-type interaction, as has been found in thiacyclo-octan-5-one.[4] Similar interactions have been studied by u.v.,[5] i.r.,[6] n.m.r.,[6,7] and photoelectron spectroscopy.[8] The importance of 1,3-through-space interactions was pointed out by Inamoto and Masuda to explain ^{13}C n.m.r. chemical shifts.[9] We have looked for model compounds which might exhibit enhanced rates of C–S bond scission as a result of a through-space interaction between a sulphur atom and a carbonyl group. This paper reports one such example, methyl 9-(ethylthio) fluorene-1-carboxylate. (It was, however, not possible to completely erase the inductive and mesomeric effects of the carbonyl group.) Enhanced rates of ester exchange and hydrolysis of the thioketal group in methyl 9,9-bis(ethylthio) fluorene-1-carboxylate were also observed. These reactions provide another intriguing example of the chemical consequences of intramolecular interactions.

Results and Discussion

C–S Bond Cleavage by Thiolate Anion.—9,9-Bis(ethylthio)-fluorenes (**2**)—(**4**) carrying a methoxycarbonyl group at the 1-, 2-, or 3-position readily reacted with sodium ethanethiolate in methanol to give 9-(ethylthio)fluorenes (**6**)—(**8**) which further reacted under the same conditions, although slowly, to give fluorene derivatives (**9**)—(**11**). Any products of the reaction must arise from the protonation of carbanions formed by the C–S bond cleavage of sulphides, in which a sulphur atom is attacked by a thiolate ion.[2,3]

The rate constants of the reactions were obtained by assuming a pseudo-first-order reaction.† The results are shown in Table 1, where the data of compounds which lack a methoxycarbonyl group are shown for comparison.

The C–S bond cleavage is accelerated when the methoxycarbonyl group is introduced to 9,9-bis(ethylthio)fluorene (**1**). Compounds (**2**)—(**4**) reacted more than 20 times faster than (**1**) and compounds (**6**)—(**8**) reacted with measurable rates, whereas (**5**) hardly reacted at all under these conditions. The second ethylthio group in (**1**)—(**4**) plays an important role in the reaction. The relative rate is larger for the 3-methoxycarbonyl compound (**4**) than for the 2-methoxycarbonyl compound (**3**). This implies that the mesomeric effect of the methoxycarbonyl group stabilizes the transition state where a partial negative charge develops at position 9. The rather slow reaction of (**2**) with the thiolate ion indicates that it is the steric effect of the 1-methoxycarbonyl group which is important in this case,

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† Assuming the reaction to be first order with respect to both substrate and nucleophile, we obtain the rate law shown by equation (1).

$$-\mathrm{d}[\mathrm{RSR'}]/\mathrm{d}t = (k[\mathrm{EtS^-}] + k'[\mathrm{EtSH}])[\mathrm{RSR'}] \qquad (1)$$

Since the rate constant for the thiolate anion must be much larger than that for the thiol, and since concentrations of the thiolate anion and the thiol are comparable, we may neglect the term due to the free thiol. The concentration of the thiolate ion is constant because the thiol exists in excess and the thiolate ion is produced as it is consumed. Equation (1) then reduces to equation (2).

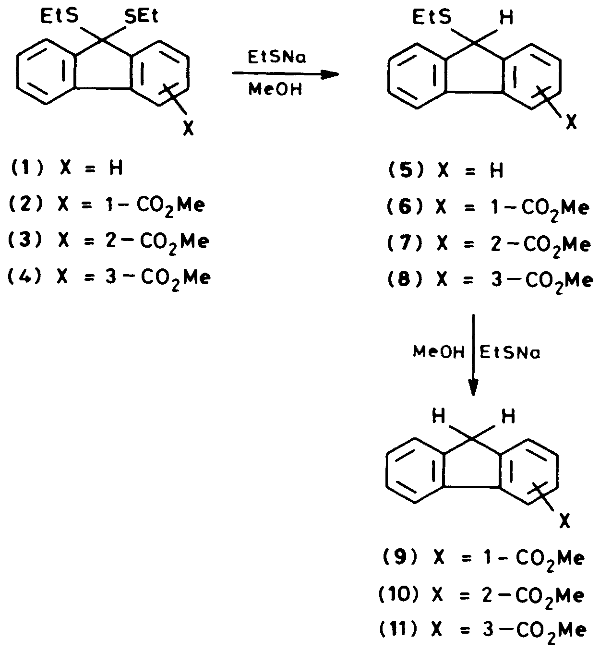
$$-\mathrm{d}[\mathrm{RSR'}]/\mathrm{d}t = k_{\mathrm{obs}}[\mathrm{RSR'}] \qquad (2)$$

The reaction is of the S_N2 type at the sulphide sulphur atom as has been previously postulated.[2] Electron-transfer mechanisms will play an important role if non-polar solvents are used for the reaction, but they will make only a small contribution in methanol. Oxygen may also have large effects on kinetics but it will be consumed easily to produce diethyl disulphide under these sealed conditions.

Table 1. Pseudo-first-order rate constants for C–S bond cleavage with sodium ethanethiolate

Run	Compd.	k_{obs}/ $s^{-1} \times 10^{-3}$	k_{rel}	EtSNa/ mol/l	T/°C
1	**(1)**	0.082	1.0	0.20	65
2	**(2)**	1.7	21	0.20	65
3	**(3)**	2.1	26	0.20	65
4	**(4)**	3.2	39	0.20	65
5	**(6)**	0.015	0.18	0.20	65
6	**(5)**	*a*		0.20	100
7	**(6)**	0.12		0.20	100
8	**(6)**	0.14		0.20	100
		av. 0.13	(5.0)[b]		
9	**(8)**	0.024		0.20	100
10	**(8)**	0.028		0.20	100
		av. 0.026	(1.0)[b]		
11	**(6)**	0.31	(12)[b]	0.40	100
12	**(7)**	0.023	(0.88)[b]	0.40	100
13	**(8)**	0.058	(2.2)[b]	0.40	100

[a] Reaction was too slow to measure the rate. [b] Relative rates are given with the average rate constant for **(8)** at 100 °C being taken as 1.0.



(1) X = H
(2) X = 1-CO_2Me
(3) X = 2-CO_2Me
(4) X = 3-CO_2Me

(5) X = H
(6) X = 1-CO_2Me
(7) X = 2-CO_2Me
(8) X = 3-CO_2Me

(9) X = 1-CO_2Me
(10) X = 2-CO_2Me
(11) X = 3-CO_2Me

rather than the electronic effect. The steric effect should reduce the S_N2 reactivity of **(2)**, in which reaction occurs at sulphur. We believe that the different reaction rate of **(2)** compared with **(3)** and **(4)** is indicative of the accelerating effect of the 1-methoxycarbonyl group.

If one looks at the relative rates in compounds **(5)**—**(8)** of the C–S scission, the role of the electronic and steric effects of the methoxycarbonyl group become clearer. While 9-(ethylthio)fluorene **(5)** itself did not react with the thiolate ion even at 100 °C, the 9-(ethylthio)fluorenes **(6)**—**(8)**, which carry a methoxycarbonyl group at the 1-, 2-, or 3-position, reacted to lose the ethylthio group: the products **(9)** and **(11)** were isolated almost quantitatively whereas **(10)** was contaminated with **(7)** because of the slow reaction. Among the compounds carrying a methoxycarbonyl group, **(7)** was the least reactive. This is because the 2-methoxycarbonyl group acts as an electron-withdrawing group mainly due to the inductive effect. Although remote, the 3-methoxycarbonyl group enhances the reactivity by a factor of 2.5 at 100 °C when one goes from **(7)** to **(8)**. This must again be attributed to the mesomeric effect of the 3-methoxycarbonyl group. Even more striking is the fact that **(6)**, which suffers from the steric effect of the methoxycarbonyl group, reacts *ca.* 5 times more easily than **(8)**, suggesting that there is a rate-enhancing mechanism other than the inductive and mesomeric effects. A direct or through-space interaction between the carbonyl group and the electron-rich centre of the transition state may be the most reasonable explanation of these results (Figure 1).

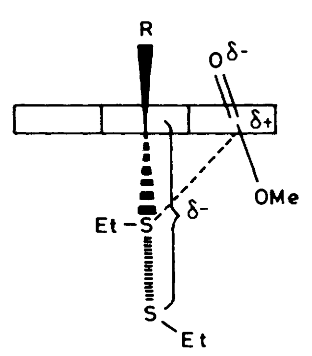


Figure 1. Proposed transition state for C–S bond cleavage (R = H, SEt).

The effect of the rate enhancement of the methoxycarbonyl group at the 1-position is not so large. This is probably due to the long distance between the methoxycarbonyl group and the sulphur atom(s) in the fluorene system. The long distance between the carbocation centre and the sulphur atoms in the dimethyl-[9,9-bis(methylthio)fluoren-1-yl]carbinyl cation system is known to prevent the formation of a sulphonium ion but to stabilize the ion.[10] The cancellation of two effects, the rate enhancement and steric hindrance of the group, is also the cause.

Ester Exchange under Basic Conditions.—During the course of the study on the C–S bond cleavage of methyl 9,9-bis(ethylthio)fluorene-1-carboxylate, we noticed that an OMe/OCD_3 ester exchange took place, although slow. This must be caused by attack of the [$^2H_3$]methoxide anion which is present in small quantities under these reaction conditions. Since the exchange reaction should take up a space-demanding transition state conformation, the rate of exchange should throw light on the steric effect which is important in **(2)**. Thus, we followed the reaction by ^1H n.m.r. spectroscopy and obtained the rate data without the addition of enthanethiol. The results are shown in Table 2.

While **(2)** reacted with a rate constant of 5.66×10^{-5} s^{-1} at 65 °C, the methoxycarbonyl group in **(3)** and **(9)** reacted much faster. The group in **(9)** reacts 280 times faster than that in **(2)**. The methoxycarbonyl group in **(3)** reacted very fast, even at 27 °C, and the reaction was complete after *ca.* 10 min. Thus, **(3)** reacts *ca.* 1 000 times faster than **(2)**, and the group in **(6)** reacts 13 times faster than that in **(2)**. If the methoxycarbonyl group approaches a tetrahedral configuration in the 1-position, the steric effect for **(2)** must be very severe, while the effect is small in the 2-position and the 1-position in **(9)**. The effect for **(6)** is smaller than that for **(2)** but is larger than that for **(3)** and **(9)**. The results are similar in the presence of ethanethiol. Whereas the ester exchange was not observed but the C–S bond cleavage did take place in **(2)**, the C–S bond cleavage and the ester exchange compete in **(3)**. The ester exchange in **(6)** was measurable, thus supporting the assumption that the steric effect of the two ethylthio groups in **(2)** is important.

Table 2. Pseudo-first-order rate constants for the ester exchange (OMe/OCD_3) under basic conditions

Compd.	$k_{obs}/s^{-1} \times 10^{-2}$	k_{rel}	$T/°C$
(9)	1.61	1.0	65.0
(6)	0.0735	0.046	65.0
(2)	0.00566	0.0035	65.0
(3)	1.0		27

Table 3. Pseudo-first-order rate constants for the ester exchange (OMe/OCD_3) under acidic conditions

Compd.	$k_{obs}/s^{-1} \times 10^{-5}$	k_{rel}	$T/$ C
$PhCO_2Me$	8.11	3.6	60.0
(9)	2.28	1.0	60.0
(12)	0.624	0.27	60.0
(6)	0.659	0.29	60.0
(2)[a]	2.8	1.2	60.0

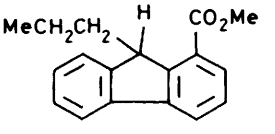
[a] Decomposition of the thioketal group was observed, see note.

Ester Exchange under Acidic Conditions.—After establishing that the intramolecular S • • • C=O interaction affects the C–S bond cleavage, we wondered whether the same interaction might affect the reactivity of the carbonyl group. As shown above, the ester exchange under basic conditions was found to be controlled by the steric effect. The next obvious step was to examine the ester exchange under acidic conditions. This reaction proved to be complicated: it involves both ester exchange and the hydrolysis of the thioketal moiety. We will first discuss the ester exchange.

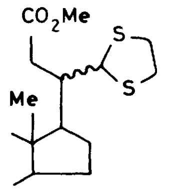
In [$^2H_4$]methanol solutions containing toluene-*p*-sulphonic acid, the methyl esters **(2)**, **(6)**, and **(9)** exchange their methoxy group with a [$^2H_3$]methoxy group. The rate constants of this were obtained at 60 °C and the results are given in Table 3 together with the data of methyl benzoate and methyl 9-propylfluorene-1-carboxylate **(12)**, for comparison. Clearly the exchange rate for methyl benzoate is larger than those of any other compounds examined. This result may be interpreted as an example of the *ortho* effect,[11–13] which is understood to be a retarding effect because of the steric requirements of the *ortho* substituent. Therefore, it may be fair to compare results among compounds whose steric requirements are similar.

The rate constants for the ester exchange of the propyl compound **(12)** and the mono(ethylthio) compound **(6)** are almost the same (Table 3). These results may be interpreted to mean that the ethylthio group has only a steric effect. In contrast, compound **(2)**, which carries two ethylthio groups, exhibits a larger rate constant than **(6)** or **(12)**, despite its severe steric conditions. Therefore the carbonyl group in **(2)** must have enhanced reactivity. We wish to attribute this enhancement to the stabilization of the protonated form shown in Figure 2.

It is puzzling at first glance why two ethylthio groups should stabilize the cation whereas one ethylthio group does not. However, there are precedents in the literature. An efficient rate-enhancing effect of an *ortho* 1,3-dithiolan-2-yl group in the acetolysis of benzyl chloride has been observed.[14] There is also a report that an ester **(13)** is easily hydrolysed.[15] The latter result is similar to the situation reported here, because the ester group and the two sulphur atoms are separated by the same number of atoms in both cases.



(12)



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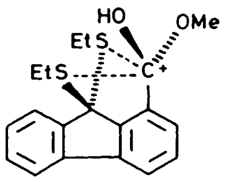
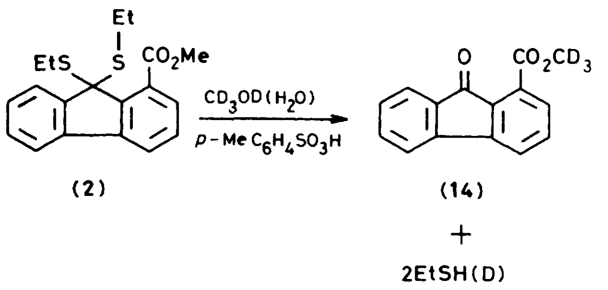


Figure 2. Stabilizing effect of sulphur atoms for the protonated ester.

Thioketal Hydrolysis.—During the ester exchange under acidic conditions, we have noticed that other reactions occur, albeit slowly. In following the reaction at 100 °C by ^1H n.m.r. spectroscopy, we found that the decomposition of the dithioketal **(2)** had a half-life of *ca.* 100 min. ^{13}C N.m.r. spectra indicated that the products were [$^2H_3$]methyl 9-oxofluorene-1-carboxylate **(14)** and ethanethiol, which further reacted to produce *S*-ethyl toluene-*p*-thiosulphonate. Formation of [$^2H_3$]methyl toluene-*p*-sulphonate was also detected.

The C–S bond scission which occurred in **(2)** to produce **(14)** was not observed for **(6)**. The results clearly indicate that the cation which is formed by removal of the ethylthio group needs stabilization, owing to the presence of another ethylthio group. This is consistent with the formation of a cation of the cyclopentadienyl type.

9,9-Bis(ethylthio)fluorene **(1)** reacted similarly under the same conditions to produce 9-fluorenone and ethanethiol. The relative rate of decomposition of **(1)** is *ca.* 0.1 if that of **(2)** is unity. In considering the electronegative effect of the methoxycarbonyl group, one would reasonably expect that the reaction of **(2)** would be slower than that of **(1)**. Since the actual results are just the opposite of this, there must be a reason for the rate enhancement for compound **(2)**. We suggest that, since there is a stabilizing effect of the S • • • C=O type in the ground state* and that such an interaction becomes stronger as the carbon atom becomes more positive, the protonated form (Figure 2) is formed easily where the migration of an ethylthio group takes place to produce a 9-cation **(15)** which then loses ethanethiol to form another cation **(16)**, a precursor to the ketone **(14)**.† In order to form a ketone, there should be water in the system. We believe this water originates from the solvent and from the water of crystallization of toluene-*p*-sulphonic acid.



(2) **(14)**

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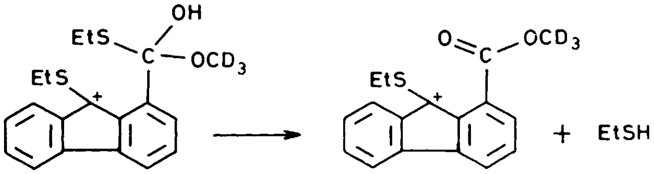
* Such interaction is rather weak in fluorene systems because of the long distance between the groups. However, see refs. 4—8.

† It is of course possible that the formation of the carbonyl group is completed before **(15)** changes to **(16)**.



(15) (16)

Table 4. ^{1}H N.m.r. spectral data of ethyl protons for compounds involved in the C–S bond cleavage of thioethers in [$^2H_4$]methanol under basic conditions[a]

Compd.	Me	CH$_2$
(1)	0.83	2.17
(2)	0.82	1.98
(3)	0.86	2.18
(4)	0.83	2.16
(5)	0.83	1.94
(6)	0.72	1.70
(7)	0.85	1.97
(8)	0.82	1.94
EtSNa•EtSH	1.35	2.54
EtSSEt	1.35	2.69

[a] The data are compiled by assuming the chemical shift of CD_2HOD to be 3.34 p.p.m. from TMS.

We have not been able to observe the presence of a thiol ester which would be formed if methanol instead of ethanethiol was removed from the intermediate (**15**). Existing literature indicates that the hydrolysis rates of thiol esters are lower than those of normal esters under acidic condtions,[16] the difference being small in aromatic esters.[17] However, the rate-determining step in the hydrolysis is the addition of a nucleophile to the carbonyl group in the esters. Ethanethiol (or ethanethiolate anion) should be a better leaving group since the remaining cation is stabilized by two oxygen atoms, whereas a cation connected to an oxygen and a sulphur atom will be less stable. This consideration is supported by the fact that the equilibrium constant of the reaction $R^1COSR^2 + R^3OH \rightleftharpoons R^1COOR^3 + R^2SH$ is large.[18]

In conclusion, we have observed rate enhancement of C–S bond cleavage by a thiolate anion, by ester exchange, and by the hydrolysis of the thioketal in methyl 9,9-bis(ethylthio) fluorene-1-carboxylate. These results are attributed to the through-space S • • • C=O interaction.

Experimental

^{1}H N.m.r. spectra were recorded at 60 MHz on a JEOL C60HL or a JEOL FX-60Q spectrometer. ^{13}C N.m.r. spectra were measured on a JEOL FX-60Q spectrometer at 15 MHz. High-resolution mass specta and i.r. spectra were obtained with a JEOL D-300 and a Hitachi model 295 spectrometer, respectively.

Methyl 9,9-*Bis*(*ethylthio*)*fluorene*-1-*carboxylate* (**2**).—To a solution of 1-methoxycarbonyl-9-fluorenone[19] (1.0 g) in ethanethiol (3 ml) was introduced dry hydrogen chloride over 2 h at 0 °C. After removal of ethanethiol, the residue was extracted with ether (200 ml). The ethereal solution was washed with aqueous sodium hydrogencarbonate and water, and dried ($CaCl_2$). After removal of the solvent, the residue was crystallized from hexane to give the *title compound* (1.26 g, 87%), m.p. 67—68 °C (Found: C, 66.0; H, 5.75%; M^+, 344.091. $C_{19}H_{20}O_2S_2$ requires C, 66.25; H, 5.85%; M, 344.090); $\delta_H(CDCl_3)$ 0.82 (6 H, t, J 7.3 Hz), 2.02 (4 H, q, J 7.3 Hz), 3.99 (3 H, s), and 7.2—8.0 (7 H, m); $\delta_C(CDCl_3)$ 13.4, 25.5, 32.0, 62.2, 119.7, 122.2, 125.3, 128.3, 128.5, 128.6, 130.9, 137.6, 140.2, 145.1, 147.2, and 168.3; $\nu_{C=O}$(Nujol) 1 740 cm^{-1}.

Methyl 9,9-*Bis*(*ethylthio*)*fluorene*-2-*carboxylate*, (**3**), was similarly prepared and was purified by chromatography on silica gel (hexane–ether 4:1 eluant), m.p. 58.5—59.5 °C (Found: C, 65.85; H, 5.65%; M^+, 344.090. $C_{19}H_{20}O_2S_2$ requires C, 66.25; H, 5.85%; M, 344.090); $\delta_H(CDCl_3)$ 0.96 (6 H, t, J 7.5 Hz), 2.25 (4 H, q, J 7.5 Hz), 3.95 (3 H, s), and 7.2—8.4 (7 H, m); $\nu_{C=O}$(Nujol) 1 737 cm^{-1}.

Methyl 9,9-*Bis*(*ethylthio*)*fluorene*-3-*carboxylate*, (**4**), was prepared and purified similarly, an oil (Found: M^+, 344.090. $C_{19}H_{20}O_2S_2$ requires M, 344.090); $\delta_H(CDCl_3)$ 0.92 (6 H, t, J 7.3 Hz), 2.21 (4 H, q, J 7.3 Hz), 3.92 (3 H, s), and 7.2—8.4 (7 H, m); $\nu_{C=O}$(Nujol) 1 734 cm^{-1}.

Methyl 9-*Propylfluorene*-1-*carboxylate*, (**12**).—To a solution of methyl fluorene-1-carboxylate[19] (1.0 g, 4.5 mmol) in dimethyl sulphoxide (15 ml) was added potassium t-butoxide (0.53 g, 4.7 mmol) at 0 °C. The mixture was stirred for 15 min and then propyl bromide (0.82 g, 6.7 mmol) in dimethyl sulphoxide (5 ml) was added dropwise. The mixture was stirred for 1 h at 0 °C and then for 1 h at 20 °C and then poured into 150 ml of ether. The mixture was washed with water and the ether layer was dried ($CaCl_2$). After evaporation of the solvent, the residue was chromatographed on silica gel (hexane–ether 4:1 eluant) to give the *title compound* (0.87 g, 73%), an oil (Found: M^+, 266.131. $C_{18}H_{18}O_2$ requires M, 266.130); $\delta_H(CDCl_3)$ 0.5—1.0 (3 H, m), 1.0—1.4 (2 H, m), 1.6—2.3 (2 H, m), 3.94 (3 H, s), 4.58 (1 H, br t, J 5 Hz), and 7.2—8.0 (7 H, m).

9-(*Ethylthio*)*fluorene* (**5**).—To a solution of (**1**) (700 mg, 2.4 mmol), which was prepared as described in the literature,[20] in methanol (5 ml) containing sodium methoxide (100 mg, 1.8 mmol), was added ethanethiol (500 mg, 8 mmol). The mixture was sealed in a test tube and heated at 100 °C for 40 h before being poured into water and the product extracted with ether. The ethereal extract was dried ($CaCl_2$) and the solvent evaporated. The residue was chromatographed on silica gel (hexane eluant) to give the pure compound,[21] m.p. 45.5—46.5 °C, almost quantitatively (Found: M^+, 226.083. Calc. for $C_{15}H_{14}S$: M, 226.082); $\delta_H(CDCl_3)$ 0.88 (3 H, t, J 7.5 Hz), 1.95 (2 H, q, J 7.5 Hz), 4.86 (1 H, s), and 7.2—7.9 (8 H, m).

A solution of 9-bromofluorene (1.0 g, 4.1 mmol) in ethanol (10 ml) was mixed with sodium ethanethiolate, prepared from sodium methoxide (4.1 mmol) and an excess of ethanethiol in ethanol (10 ml). The reaction mixture, after being allowed to stand for 40 h, was treated as above to afford (**5**) (42% yield).

Reaction of Methyl 9,9-*Bis*(*ethylthio*)*fluorene*-1-*carboxylate* (**2**) *with Sodium Ethanethiolate*.—A portion of a methanolic solution (15 ml) containing (**2**) (0.50 g, 1.5 mmol), sodium methoxide (0.30 g, 5.6 mmol), and ethanethiol (0.50 g, 8 mmol) were sealed in a test tube and the mixture was heated at 65 °C for 1.5 h. The solution was poured into ether (150 ml) and the mixture was washed with cold water. The ethereal solution was dried ($CaCl_2$) and the solvent evaporated. The residue was submitted to chromatography on silica gel (hexane–ether 4:1 eluant) to give pure *methyl* 9-(*ethylthio*)*fluorene*-1-*carboxylate* (0.30 g, 92%), m.p. 62—63 °C (Found: C, 71.85; H, 5.5%. $C_{17}H_{16}O_2S$ requires C, 71.80; H, 5.67%); $\delta_H(CDCl_3)$ 0.74 (3 H, t, J 7.5 Hz), 1.72 (2 H, q, J 7.5 Hz), 4.00 (3 H, s), 5.45 (1 H, s), and 7.2—7.9 (7 H, m).

When a solution, whose composition was the same as shown above, was heated at 100 °C for 20 h, the product in almost quantitative yield was methyl 1-fluorenecarboxylate (**9**), m.p. 86—87 °C (lit.,[19] 86.6—87.4 °C). The following ^{1}H n.m.r. data

($CDCl_3$) were recorded; δ 3.97 (3 H, s), 4.25 (2 H, s), and 7.2—8.1 (7 H, m).

Kinetic Measurement of the C–S Bond Cleavage under Basic Conditions.—A thioether (0.050 mmol) and sodium methoxide (0.10 or 0.20 mmol) were dissolved in [$^2H_4$]methanol (0.50 ml) and ethanethiol (*ca.* 0.3 mmol) was added to the solution. The solution was sealed in an n.m.r. tube. The ^1H n.m.r. spectra exhibited peaks due to the ethylthio groups, as shown in Table 4. The solution was heated at 65 or 100 °C according to the reactivity of the substrate. The temperature was maintained at 65.0 ± 0.1 or 100.0 ± 0.2 °C. The ethyl signals of the thioether, ethanethiol, and diethyl disulphide were monitored by ^1H n.m.r. spectroscopy.

When the reaction was continued further to produce (**9**)—(**11**), ethanethiol of the amount corresponding to the loss due to the reaction was added to the mixture, if necessary.

Methyl 9-(ethylthio)fluorene-3-carboxylate (**8**) was not isolated but its formation was assumed from the appearance of new ethyl signals in ^1H n.m.r. spectra (see Table 4) and by analogy with the reaction of (**2**). Further reaction of (**8**) with ethanethiolate afforded methyl fluorene-3-carboxylate (**11**), m.p. 77—79 °C (lit.,[22] 79—80 °C). Its ^1H n.m.r. spectrum ($CDCl_3$) was consistent with the structure; δ 3.92 (2 H, s), 3.95 (3 H, s), and 7.2—7.5 (7 H, m).

Intervention of methyl 9-(ethylthio)fluorene-2-carboxylate (**7**) in the reaction of (**3**) with ethanethiolate was assumed by analogy with other reactions and ^1H n.m.r. spectra (see Table 4).

Further reaction of (**7**) with ethanethiolate caused appearance of signals due to methyl fluorene-2-carboxylate, $\delta_H[(CD_3)_2SO]$ 3.89 (3 H, s), 3.97 (2 H, s), and 7.2—8.4 (7 H, m).

The results were treated on the assumption of pseudo-first-order kinetics. Indeed, good linear relationships were observed until *ca.* 70% completion of the reaction and errors are *ca.* ±10% except for (**7**), when the reaction was followed until 50% completion. These results are shown in Table 1.

Kinetic Measurement of the Ester Exchange under Basic Conditions.—A solution of an ester (0.20 mmol) and sodium methoxide (0.30 mmol) in [$^2H_4$]methanol (1.5 ml) was sealed in an n.m.r. sample tube. The solution was heated at 65.0 °C and the thermostat temperature was maintained at 65.0 ± 0.1 °C. The intensity of the signal due to the methoxycarbonyl protons was followed. For compounds (**2**), (**6**), and (**9**), linear relationships were very good and errors were ±7—10%. In the case of (**3**), the ester exchange was very fast even at an n.m.r. probe temperature of 27 °C (half-life *ca.* 1 min). These results are given in Table 2.

The ester exchange was also observed during the kinetic measurement of the C–S bond cleavage by sodium ethanethiolate in [$^2H_4$]methanol.

Kinetic Measurement of the Ester Exchange under Acidic Conditions.—A methyl ester (0.10 mmol) and toluene-*p*-sulphonic acid dihydrate (0.20 mmol) were dissolved in [$^2H_4$]methanol (0.50 ml) and the solution was sealed in an n.m.r. sample tube. The solution was heated at 60.0 °C and the temperature was maintained at 60.0 ± 0.1 °C. The reactions were followed as above. The results are shown in Table 3.

A reaction simultaneous with the ester exchange was noticed, which was slower than the ester exchange by a factor of *ca.* 0.25 at 60 °C. This reaction was followed by ^{13}C n.m.r. spectroscopy (the data are shown on the assumption that the ^{13}C signal of [$^2H_4$]methanol appears at 49.0 p.p.m.) at 100 °C (half-life *ca.* 100 min). New signals which grew as the reaction of methyl 9,9-bis(ethylthio)fluorene-1-carboxylate proceeded were observed at 192.6, 19.5, and 20.2 p.p.m. The signals at 19.5 and 20.2 p.p.m. were found to be due to ethanethiol and that at 192.6 p.p.m. due to methyl 9-oxofluorene-1-carboxylate. The spectra also indicated the formation of *S*-ethyl toluene-*p*-thiosulphonate (8.8 and 38.5 p.p.m.) and [$^2H_3$]methyl toluene-*p*-sulphonate (59.7 p.p.m.).

9,9-Bis(ethylthio)fluorene (**1**) reacted similarly to give a signal at 195.3 p.p.m. in its ^{13}C n.m.r. spectrum, which corresponded to fluoren-9-one. The half-life of (**1**) was *ca.* 1 000 min under these conditions. Similar treatement of methyl 9-(ethylthio)-fluorene-1-carboxylate (**6**) did not result in any appreciable reaction.

Although the ester exchange of (**2**) proceeded with the hydrolysis of the thioketal group, the linear relationship was good until 50% completion of the reaction compared with those of others in Table 3 which were very good until *ca.* 70% completion of the reaction. Errors for the latter are ±7—10% and that for (**2**) may be *ca.* ±10%.

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