described, was partially dissolved in 20 ml. of dimethyl sulfoxide, filtered, and precipitated with 100 ml. of heptane. This produced about 100 mg. of a light yellow compound having the same melting point as the tan substance obtained before.

Hindered carbonyl compounds such as 2-hydroxyacetophenone and 4,6-dimethoxy-2-hydroxybenzaldehyde were treated exactly like the compounds of the 1 to 5 series, except that the reaction time was extended to 3 hours, but did not give biscoumarins. NMR analysis indicated that the products were 4-methyl-3-hydroxycoumarin acetate and 5,7-dimethoxy-3-hydroxycoumarin acetate. Analyses from three repeated preparations gave acceptable carbon, but hydrogen determinations were consistently 1% too high.

ACKNOWLEDGMENT

Analyses were performed by George I. Robertson, 73 West End Ave., Florham Park, N. J. 07932. The authors acknowledge with thanks the financial support by the Robert A. Welch Foundation.

RECEIVED for review August 22, 1969. Accepted February 6, 1970.

Derivatives of Thionyl Imide

JOSEPH M. KANAMUELLER
Department of Chemistry, Western Michigan University, Kalamazoo, Mich. 49001

The reaction of thionyl chloride with H_2NNR_2 (R = alkyl) yields derivatives of thionyl imide with the formula $OSNNR_2$. Infrared and proton NMR spectral data are given. *N*-(Dimethylamino)thionyl imide did not react with methyl iodide. This is attributed to electron delocalization, hence a lack of basic sites, in the molecule of the thionyl imide derivative.

THIONYL IMIDE, $O{=}S{=}N{-}H$, can be synthesized in the gas-phase reaction of thionyl chloride and ammonia (*8*). The monomeric form is unstable and polymerizes readily. However, derivatives with the formula $O{=}S{=}N{-}R$ (R = organic group) do not show the instability of the parent compound (*2*). These have been referred to as thionyl imines as well as sulfinyl amines. Work by Michaelis had established the existence of compounds with the general formula $O{=}S{=}N{-}N(R)C_6H_5$ (R = H, CH_3, $CH_2C_6H_5$) (*4, 5, 6*). The compounds had been named as sulfinyl hydrazines; however, they should be considered derivatives of thionyl imide. More recently, Klamann *et al.* prepared the same compounds with a modification of the procedure of Michaelis (*3*). The general method was the reaction of thionyl chloride with the substituted hydrazine (phenylhydrazine, 1-phenyl-1-methylhydrazine, and 1-phenyl-1-benzylhydrazine) in chloroform in the presence of pyridine. Middleton used a transthionylation reaction to prepare thionyl imide derivatives (*7*). This was also a procedure used by Michaelis.

This investigation was undertaken to extend the series of known compounds containing the $O{=}S{=}N{-}N$ group. Compounds containing only alkyl substituents were prepared, but only with further modifications of previously used procedures.

EXPERIMENTAL

Materials. 1,1-Dimethylhydrazine (J. T. Baker Chemical Co.) was distilled and stored over potassium hydroxide (b.p. 63° C.). Triethylamine (Matheson, Coleman and Bell) was distilled and stored over calcium hydride (b.p. 90° C.). Pyridine was used as obtained from Allied Chemical. Thionyl chloride (Matheson, Coleman and Bell) was fractionated using a 30-mm. column filled with Raschig rings. The middle fraction (b.p. 76–78° C.) was reserved in a tightly closed flask in a refrigerator until use. *N*-Aminopiperidine and *N*-aminohomopiperidine (Aldrich Chemical Co.) were distilled prior to use (b.p. 70° C. at 50 mm., 100° C. at 50 mm., respectively). *N*-Aminomorpholine, also obtained from Aldrich Chemical Co., was used as received. Diethyl ether and benzene were dried with calcium hydride, chloroform with calcium chloride.

Analyses. Elemental analyses were performed by A. Bernhardt Mikroanalytisches Laboratorium, Elbach über Engelskirchen, West Germany. Melting points were determined in capillary tubes using a Thomas-Hoover melting point apparatus. A Beckman IR 8 was used to record the infrared spectra. The NMR spectra were obtained on a Varian A-60 spectrometer. Tetramethylsilane was the internal standard for all samples.

Preparation of *N*-(Dimethylamino)thionyl Imide, $OSNN(CH_3)_2$. A 500-ml. three-necked flask was equipped with a vapor seal stirring apparatus, a KOH-filled drying tube, and a 125-ml. pressure-equalizing dropping funnel. A solution of 22.8 ml. of 1,1-dimethylhydrazine (18.0 grams, 0.30 mole), 84 ml. of triethylamine (60.6 grams, 0.60 mole), and 300 ml. of anhydrous ether was prepared in the flask. To this was added over a period of 3 hours with stirring and ice bath cooling, a solution of 21.6 ml. of thionyl chloride (35.7 grams, 0.30 mole) in 50 ml. of anhydrous ether. A pale yellow solution with a white solid resulted. After the reaction mixture had come to room temperature, the solid, triethylamine hydrochloride, was quickly filtered from the solution and dried in vacuo. A nearly quantitative yield was obtained [m.p. 245–54° C., lit. 254° C. (*1*)]. The ether was removed from the filtrate with a flash evaporator. Distillation of the resulting yellow liquid (88° C., 50 mm.) gave 18.4 grams (58% of theory) of *N*-(dimethylamino)-thionyl imide. The compound is soluble in water as well as in the common organic solvents. Analytical and spectral data are given in Tables I, II, and III.

Dry benzene can also be used as a solvent for the reaction. Chloroform is also suitable. However, since triethylamine

Table I. Reactions of Thionyl Chloride with Substituted Hydrazines

Hydrazine	Product	Color	B. P., ° C./Mm.	Yield, %	H^1 NMR τ (P.P.M.)
$(CH_3)_2NNH_2$	$OSNN(CH_3)_2$	Yellow	88/50	58	6.58[a]
$(CH_2)_5NNH_2$	$OSNN(CH_2)_5$	Yellow	48-50/0.2	58	6.10(N—CH_2)[b,c] 8.30(C—CH_2)
$(CH_2)_6NNH_2$	$OSNN(CH_2)_6$	Yellow	62/0.1	54	6.02(N—CH_2)[b,c] 8.29(C—CH_2)
$O(CH_2CH_2)_2NNH_2$	$OSNN(CH_2CH_2)_2O$		50.5-52.5[d]	96	6.07[b]

[a] CCl_4 solution. [b] $CDCl_3$ solution. [c] Multiplets. [d] Melting point; pale yellow crystals recrystallized from cyclohexane.

Table II. Analytical Data for Thionyl Imide Derivatives

	% C		% H		% N		% S	
Compound	Calcd.	Found	Calcd.	Found	Calcd.	Found	Calcd.	Found
$OSNN(CH_3)_2$	22.64	22.54	5.70	5.64	26.38	26.41	30.21	30.05
$OSNN(CH_2)_5$	41.07	41.27	6.89	6.89	19.16	19.07	21.93	22.14
$OSNN(CH_2)_6$	45.00	45.19	7.56	7.61	17.50	17.51	20.01	19.79
$OSNN(CH_2CH_2)_2O$	32.13	32.24	5.44	5.46	18.91	18.91	21.63	21.51

Table III. Infrared Spectral Data (Cm.$^{-1}$)[a]

$OSNN(CH_3)_2$[b]

2920(m), 2850(sh), 2800(sh), 1480(m), 1400(m), 1410(w), 1360(s), 1185(s), 1130(w), 1060(vs), 905(w, br), 740(s)

$OSNN(CH_2)_5$[b]

2930(s), 2850(m), 1440(m), 1370(m), 1320(sh), 1270(w), 1230(s), 1140(s), 1080(vs), 1010(s), 985(s), 950(w), 920(w), 885(w), 848(m), 715(m), 642(w, br)

$OSNN(CH_2)_6$[b]

2930(s), 2850(m), 1450(m), 1390(s), 1385(sh), 1300(w), 1260(m), 1210(w), 1180(w, br), 1105(sh), 1080(vs), 1040(sh), 1010(m), 990(sh), 965(w), 900(w, br), 880(w, br), 850(w, br), 765(w, br), 710(m)

$OSNN(CH_2CH_2)_2O$[c]

2975(m), 2900(m), 2850(s), 1450(m), 1430(m), 1360(m), 1310(w), 1290(sh), 1275(m), 1225(m), 1210(sh), 1185(w), 1115(s), 1085(s), 1025(sh), 1015(s), 930(w), 905(m), 845(m), 665(s)

[a] s, strong; v, very; m, medium; w, weak; br, broad; sh, shoulder. [b] Capillary film between salt plates. [c] Fluorolube and mineral oil mulls.

hydrochloride is appreciably soluble in chloroform, the addition of ether is necessary to precipitate the hydrochloride quantitatively.

Reaction of Thionyl Chloride and 1,1-Dimethylhydrazine in Presence of Pyridine. This reaction was carried out under conditions described above, with the following exceptions. Chloroform was used as the reaction solvent and pyridine (48.4 ml., 47.5 grams, 0.60 mole) as the HCl acceptor. During addition of the thionyl chloride, gas evolution was noticed. Very little (0.6 gram) of the desired product, $OSNN(CH_3)_2$, resulted but rather decomposition products, among which were elemental sulfur and sulfur dioxide.

Preparation of Other Derivatives of Thionyl Imide. The procedure described for the preparation of *N*-(dimethylamino)thionyl imide was used to prepare *N*-(piperidino)thionyl imide, $OSNN(CH_2)_5$, *N*-(homopiperidino)thionyl imide, $OSNN(CH_2)_6$, and *N*-(morpholino)thionyl imide, $OSNN(CH_2CH_2)_2O$. The results and analytical and spectral data are summarized in Tables I, II, and III.

Attempted Reaction of CH_3I with $OSNN(CH_3)_2$. One gram of $OSNN(CH_3)_2$ (9.5 mmoles) and 1.34 grams of CH_3I (9.5 mmoles) in 25 ml. of ether were refluxed for approximately 18 hours. No evidence of compound formation was observed. Other attempts to achieve reaction were carried out using refluxing benzene and a large excess of CH_3I. No new compound was found. The starting materials were recovered after these attempts, with some decomposition.

DISCUSSION

Derivatives of thionyl imide containing -*N*(alkyl)$_2$ groups were prepared from the reactions of thionyl chloride with substituted hydrazines. The general equation for the reaction is

$$OSCl_2 + H_2NNR_2 + 2(C_2H_5)_3N \rightarrow OSNNR_2 + 2(C_2H_5)_3N \cdot HCl$$

To achieve this, however, it is necessary to employ triethylamine as the tertiary base or HCl acceptor. Pyridine was unsuitable, resulting in decomposition products rather than the desired thionyl imide derivative. Data do not appear to be available to compare base strengths in the solvents used. The aqueous system shows a large difference between the base strengths; thus one may be tempted to conclude that this is the driving force or primary factor in the reaction. Such a statement, however, is only speculative at this time.

The infrared spectra of the new compounds show strong absorption bands in the regions 1115 to 1185 and 1060 to 1085 cm.$^{-1}$ These can be assigned to ν_{as} (NSO) and ν_s (NSO), respectively. This is in good agreement with the assignments made for the other known thionyl imide derivatives (*3*). The proton NMR spectra are also consistent with the proposed formulas. Both the piperidino and homopiperidino derivatives show methylene groups attached to nitrogen as well as carbon atoms. The morpholino derivative shows a single absorption, indicating no difference between the methylene groups attached to nitrogen or oxygen atoms.

The failure of methyl iodide to react with $OSNN(CH_3)_2$ can possibly be explained by steric hindrance or a lack of basic sites on the nitrogen atoms. Steric effects seem less likely to be the reason for failure of the reaction to occur. Hydrazines and amines are known to alkylate readily and form quaternary salts with methyl iodide—for example, $(CH_3)_2NNH_2$ adds CH_3I to form $[(CH_3)_3N^+NH_2]I^-$, with no special conditions required. The second possibility, a lack of basic nitrogen sites, seems to be a more attractive explanation for the failure of reaction. Consider three possible resonance structures:

$$O{=}S{=}N{-}N(CH_3)_2 \leftrightarrow O{=}S^-{-}N{=}N^+(CH_3)_2 \leftrightarrow$$
$$^-O{-}S{\equiv}N^+{-}N(CH_3)_2$$

Extensive electron delocalization could occur. In addition, the vacant *d* orbitals on sulfur could participate in a π-bonding scheme involving unshared electron pairs on neighboring atoms. Thus the electron pairs that might normally be considered sites of attack by methyl iodide are delocalized, so that they are no longer available for reaction.

LITERATURE CITED

(1) "Handbook of Chemistry and Physics," 45th ed., p. C-113, Chemical Rubber Publishing Co., Cleveland, 1964.
(2) Houben-Weyl, "Methoden der organischen Chemie," Vol. **XI/2**, pp. 73 ff., Verlag Georg Thieme, Stuttgart, 1958.
(3) Klamann, D., Krämer, U., Weyerstahl, P., *Chem. Ber.* **95**, 2694 (1962).
(4) Michaelis, A., *Ber. Deut. Chem. Ges.* **22**, 2228 (1889).
(5) *Ibid.*, **24**, 745 (1891).
(6) Michaelis, A., Ruhl, J., *Ibid.*, **23**, 474 (1890).
(7) Middleton, W. J., *J. Am. Chem. Soc.* **88**, 3842 (1966).
(8) Nickless, G., Ed., "Inorganic Sulfur Chemistry," pp. 491–3, Elsevier, New York, 1968.

RECEIVED for review September 11, 1969. Accepted December 5, 1969. Work supported in part by a Frederick Gardner Cottrell grant from Research Corp. and by the Faculty Research Fund, Western Michigan University.

Dicyclohexylcarbodiimide-Mediated Sulfation of Alkanethiols

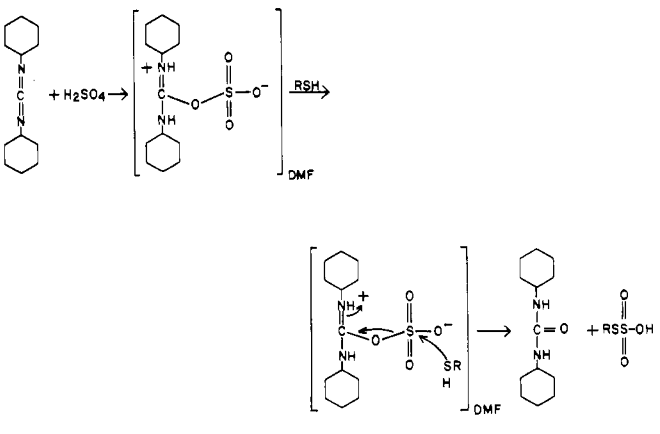
New Method for Preparation of Organic Thiosulfates

RALPH O. MUMMA, KAZUYOSHI FUJITANI[1], and CHARLES P. HOIBERG
The Pesticide Research Laboratory and Graduate Study Center, Departments of Entomology and Biochemistry,
The Pennsylvania State University, University Park, Pa. 16802

Octyl, dodecyl, hexadecyl, benzyl, and cyclohexyl thiosulfates were synthesized by the reaction of sulfuric acid with alkanethiols and dicyclohexylcarbodiimide in the solvent dimethylformamide. The formation of these organic thiosulfates was highly dependent upon the ratio and concentration of the reactants. The thiosulfates were isolated by ion-exchange chromatography. A mechanism for the reaction is proposed.

ORGANIC THIOSULFATES (Bunte salts) have been studied for many years. Their synthesis and reactions have recently been summarized (*4*). Bunte salts are extensively used in the dye industry and show considerable medicinal potential as antiradiation agents. The isolation of several naturally occurring organic thiosulfates has stimulated biochemical interest (*1, 5, 7, 8*).

Alkyl thiosulfates have been prepared by the reaction of an alkyl halide with thiosulfate ion, the reaction of sulfite or bisulfite ion with a disulfide or hydrodisulfide, and the reaction of chlorosulfonic acid or sulfur trioxide adducts with an alkanethiol. Previously, we reported the radiochemical synthesis of compounds possessing chemical properties of organic thiosulfates (*2*). Further investigation has confirmed the proposed structures and allows us now to report the synthesis of alkyl thiosulfates by this new method, the dicyclohexylcarbodiimide-mediated sulfation of alkanethiols.



EXPERIMENTAL

Material and Methods. The solvents, alkanethiols, and alkyl halides were purified by distillation. Their purity was determined by gas chromatography and thin-layer chromatography (Supelcosil-12B, Supelco, Inc.) (benzene–diethyl ether–ethanol–acetic acid; 50:40:2:0.2, v./v.). The thiosulfates were analyzed by thin-layer chromatography (chloroform-methanol-water; 65:25:4, v./v.) and the plates were stained with iodine and charred with a 20% perchloric acid spray. Infrared spectra were obtained with a Perkin-Elmer 521 spectrophotometer (Nujol). A Bendix Time of Flight mass spectrometer was used for the laser ionization mass spectra of the thiosulfates. Elemental analyses were performed by Midwest Microlab, Inc., Indianapolis, Ind. Whatman diethylaminoethylcellulose (DE-11) and Dowex 50W-X8 columns were used as ion exchangers.

General Procedure for Preparation of Sodium Alkyl Thiosulfates by DCC-Mediated Sulfation of Alkanethiol. DCC (21.7 mmoles) was dissolved in 6.68 ml of DMF and added to a solution of 4.0 mmoles of alkanethiol (1-octanethiol, 1-dodecanethiol, 1-hexadecanethiol, α-toluenethiol, 2-naphthalenethiol, and cyclohexanethiol) in 5 ml of DMF. To this swirled solution (0°) was added dropwise 5 ml of DMF containing 4.48 mmoles of concentrated H_2SO_4 (molar ratio of reactants: 5.44:1:1.12, DCC:RSH:H_2SO_4). The reaction mixture was occasionally shaken for 15 minutes and then 4 ml of H_2O was added to convert any unreacted DCC to dicyclohexylurea. The entire mixture was immediately placed on a DEAE-cellulose column (Cl^- form, 5 grams of DEAE-cellulose, 2.6-cm diameter) and eluted with 2 liters of methanol. The unreacted alkanethiol and the relatively insoluble dicyclohexylurea were eluted with the excess methanol. The thiosulfate ester was then eluted from the DEAE-cellulose column with 250 ml of methanolic ammonium hydroxide (14.8*M* NH_4OH-methanol; 1:9, v./v.) and the eluate was immediately evaporated to dryness under

---

[1] Present address, Faculty of Pharmaceutical Sciences, Kyoto University, Kyoto, Japan.