

rate of reactivity rather than to a change in equilibrium reactivity. The USP acid-consuming capacity test is based on the amount of acid neutralized by the gel in 1 hr. Thus, the acid reactivity measured by the USP test decreased during aging, although the equilibrium reactivity of the gels was unchanged.

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# IR Spectroscopic Characterization of 2-Thiohydantoins and 2-Thiobarbiturates

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**Abstract** □ A characterization of 2-thiohydantoins and 2-thiobarbiturates by IR spectra is proposed, using three characteristic group frequencies: the "thioureide band" around 1500  $\text{cm}^{-1}$  and the antisymmetric-symmetric stretching modes of NCS bonds around 1400 and 1200  $\text{cm}^{-1}$ . The general characteristic absorption areas are found by comparison with *N*-phenylthioureas and thioanilides.

**Keyphrases** □ Thiouhydantoins—characterization by IR spectroscopy □ Thiobarbiturates—characterization by IR spectroscopy □ IR spectroscopy—characterization of thiohydantoins and thiobarbiturates

Whereas the origin and localization of the characteristic group frequencies of the carbonyl in hydantoins (1) and barbiturates (2) have been thoroughly studied, the question is still open for the corresponding thio compounds because of difficulties in assignments. Strong coupling occurs between the C-S and C-N vibrations, resulting in numerous bands in the 1550–1200- $\text{cm}^{-1}$  region, each of which contains a significant contribution from the C=S stretching mode (3).

The identification in the literature is often based on the "thioureide band," as defined previously (4, 5), in spite of the absence of a C=S contribution to this mode<sup>1</sup>.

A new characterization of the thiohydantoins and thiobarbiturates series by IR spectra, involving the antisymmetric and symmetric stretching modes of NCS bonds, is now reported.

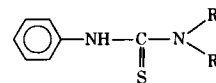
## EXPERIMENTAL

IR spectra were recorded<sup>2</sup> using the potassium bromide pellets technique (1 mg/200 mg) after the compounds were dried overnight under vacuum (0.2 mm Hg at 60°). The structures of utilized compounds were confirmed by comparison with literature data or by mass

<sup>1</sup> The "thioureide band" is due to a  $\nu_{\text{C-N}}$  mode; coupling between  $\nu_{\text{C-N}}$  and  $\delta_{\text{NH}}$  may occur in suitable cases. This band is designated as the B band in the classification of Jensen and Nielsen (5).

<sup>2</sup> Perkin-Elmer model 621.

Table I—Characteristic Bands (Centimeters<sup>-1</sup>) of *N*-Phenylthioureas



Compound		$\nu_{\text{thioureide}}$	$\nu_{\text{as}} \text{NCS} / \nu_{\text{s}} \text{NCS}^a$
I	$R_1 = \text{H}, R_2 = \text{H}$	1530	1450/1232
II	$R_1 = \text{H}, R_2 = \text{C}_6\text{H}_5$	1555	1452/1245
III	$R_1 = \text{C}_6\text{H}_5, R_2 = \text{C}_6\text{H}_4\text{—OCH}_3$	1550	1450/1240
IV	$R_1 = R_2 = \text{cyclo-(CH}_2)_5$	1540	1440/1230
V	$R_1 = \text{H}, R_2 = \text{C}_6\text{H}_5\text{—CH}_2\text{—CH—CH}_3$	1538	1450/1245
VI	$R_1 = \text{CH}_3, R_2 = \text{C}_6\text{H}_5\text{—CH(OH)—CH—CH}_3$	1538	1450/1260
VII	$R_1 = \text{H}, R_2 = \text{cyclo C}_6\text{H}_{11}\text{—CH—COOH}$	1515	1410/1230

<sup>a</sup>  $\nu_{\text{as}} \text{NCS}$  and  $\nu_{\text{s}} \text{NCS}$  designate the antisymmetric and symmetric stretching modes of the NCS function.

spectrometry<sup>3</sup> (ionization potential of 70 eV).

*N*-Phenylthioureas (I–VII) were obtained by interaction of phenyl isothiocyanate and amines in ether and subsequent recrystallization in methanol (6). The properties of I–IV (6) and VII (7) were in agreement with the literature.

Compound V had a melting point of 104–107°;  $m/e$  270 ( $M^+$ ), 236 ( $-\text{H}_2\text{S}$ ), 145 [ $\text{C}_6\text{H}_5\text{CH}_2\text{CH}(\text{CH}_3)\text{NC}$ ], 135 ( $\text{C}_6\text{H}_5\text{NCS}$ ), 91 ( $\text{C}_6\text{H}_5\text{CH}_2$ ), and 77 ( $\text{C}_6\text{H}_5$ ). Compound VI had a melting point of 114–117°;  $m/e$  282 ( $-\text{H}_2\text{O}$ ), 264 ( $-\text{H}_2\text{S}$ ), 207 ( $\text{C}_6\text{H}_5\text{NH}_2$ ), 145

<sup>3</sup> LKB 900 S.

**Table II—Characteristic Bands (Centimeters<sup>-1</sup>) of 2-Thiohydantoin**

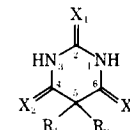
Compound	$\nu_{C=O}$	$\nu_{\text{thioureide}}$	$\nu_{\text{as NCS}}/\nu_{\text{s NCS}}^a$
VIII	1740	1510	1430/1250
IX	1735	1500	1440/1240
X	1745	1490	1430/1245
XI	1755	1510	1445/1240
XII	1750	1485	1445/1230
XIII	1730	1500	1445/1245
XIV	1760	1520	1445/1240
XV	1770	1470	1410/1210
XVI	1765	1470	1410/1210
XVII	1750	1530	1445/1220
XVIII	1740	1512	1445/1225
XIX	1730	1530	1450/1220

<sup>a</sup>  $\nu_{\text{as NCS}}$  and  $\nu_{\text{s NCS}}$  designate the antisymmetric and symmetric stretching modes of the NCS function.

**Table III—Characteristic Bands (Centimeters<sup>-1</sup>) of Thiobarbiturates**

Compound	$\nu_{\text{thioureide}}$	$\nu_{\text{as NCS}}/\nu_{\text{s NCS}}^a$
XX	1545	1425/1225 (2-thio)
XXI	1535	1420/1215 (2-thio)
XXII	1535	1418/1215 (2-thio)
XXIII	1530	1420/1210 (2-thio)
XXIV	1510	1410/1200 (2-thio)
XXV	—	1455/1248 (4-thio)
XXVI	1545	1432/1225 (2-thio) 1448/1240 (4-thio)
XXVII	—	1445/1225 (4,6-dithio) 1442/1175 (4,6-dithio)
XXVIII	1540	1440/1225 (2-thio) 1460/1245 (4,6-dithio) 1435/1190 (4,6-dithio)

<sup>a</sup>  $\nu_{\text{as NCS}}$  and  $\nu_{\text{s NCS}}$  designate the antisymmetric and symmetric stretching modes of the NCS function.



[C<sub>6</sub>H<sub>5</sub>CH<sub>2</sub>CH(CH<sub>3</sub>)NC], 135 (C<sub>6</sub>H<sub>5</sub>NCS), 91 (C<sub>6</sub>H<sub>5</sub>CH<sub>2</sub>), and 77 (C<sub>6</sub>H<sub>5</sub>).

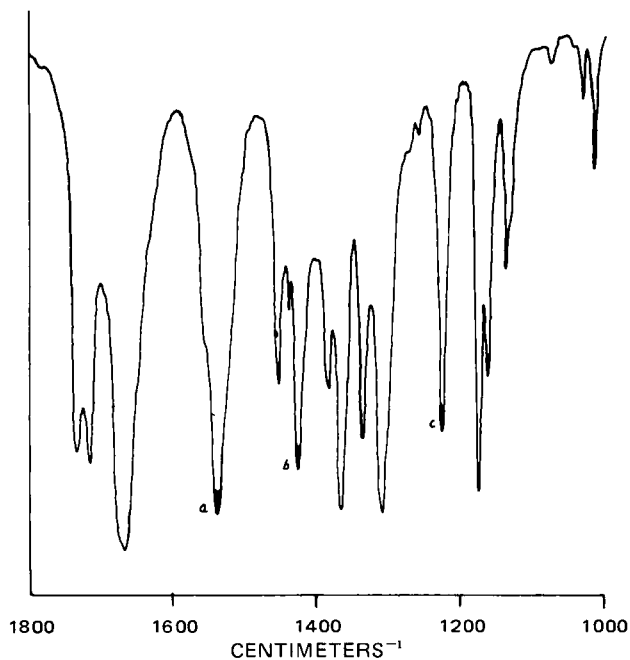
2-Thiohydantoin was prepared according to standard procedures from the literature. Compounds VIII–XII and XIV were synthesized by Edman's (8) method; XII and XIII were prepared according to the procedure of Elmore (4); XV, XVI, and XIX were obtained by Carington's (9) procedures. Compound XVIII was obtained by thionation of the corresponding hydantoin with phosphorus hemipentasilfide in refluxing dioxane. Compound XVII was the commercial product<sup>4</sup>. Properties of VIII, IX (7), XII (10), and XIV (11) were in

agreement with the literature.

Compound X had a melting point of 245–246°; *m/e* 274 (M<sup>+</sup>), 245 (—COH), 192 (C<sub>6</sub>H<sub>10</sub>), 135 (C<sub>6</sub>H<sub>5</sub>NCS), 104 (C<sub>6</sub>H<sub>5</sub>CNH), and 77 (C<sub>6</sub>H<sub>5</sub>). Compound XI had a melting point of 229–231° dec.; *m/e* 268 (M<sup>+</sup>), 239 (—COH), 149 (C<sub>6</sub>H<sub>5</sub>CH<sub>2</sub>NCS), 135 (C<sub>6</sub>H<sub>5</sub>NCS), 104 (C<sub>6</sub>H<sub>5</sub>CNH), and 77 (C<sub>6</sub>H<sub>5</sub>). Compound XIII had a melting point of 251–253°; *m/e* 350 (M<sup>+</sup>), 268 (C<sub>6</sub>H<sub>10</sub>), 135 (C<sub>6</sub>H<sub>5</sub>NCS), 104 (C<sub>6</sub>H<sub>5</sub>CNH), and 77 (C<sub>6</sub>H<sub>5</sub>).

Compound XV had a melting point of 195–196° dec.; *m/e* 234 (M<sup>+</sup>), 206 (—CO), 163 (C<sub>6</sub>H<sub>5</sub>CHNCSNH), 105 (C<sub>6</sub>H<sub>5</sub>CHNH), and 77 (C<sub>6</sub>H<sub>5</sub>). Compound XVIII had a melting point of 290–292°; *m/e* 274 (M<sup>+</sup>), 245 (—CHO), 240 (—H<sub>2</sub>S), 192 (C<sub>6</sub>H<sub>10</sub>), 84 (C<sub>6</sub>H<sub>10</sub>, C<sub>6</sub>H<sub>5</sub>), and

<sup>4</sup> Aldrich D 21, 425–6.



**Figure 1**—IR spectrum of 2-thiobarbital in potassium bromide pellet. Key: a, thioureide band; b, antisymmetric stretching mode of NCS; and c, symmetric stretching mode of NCS.

77 (C<sub>6</sub>H<sub>5</sub>).

2-Thiobarbiturates XX<sup>5</sup>, XXI<sup>6</sup>, XXII<sup>7</sup>, XXIII<sup>8</sup>, and XXIV<sup>9</sup> were commercial products. Thiobarbiturates XXV–XXVIII were described previously (2).

## RESULTS AND DISCUSSION

On the assumption that similar structures of thiourea derivatives, including the NC(=S)N sequence in different surroundings, would present only slight modifications in their NCS antisymmetric and stretching modes, 2-thiohydantoins can be regarded as cyclic monoacylthioureas and 2-thiobarbiturates can be regarded as cyclic diacylthioureas.

According to the study of Davies and Jones (12), the NCS antisymmetric and symmetric stretching modes were tentatively assigned at 1452–1410 and 1260–1230 cm<sup>-1</sup>, respectively, in a series of *N*-phenylthioureas (I–VII) (Table I). This value was in good agreement with the observed C and D bands<sup>10</sup> in the extensive work of Jensen and Nielsen (5).

In a series of seven 3-phenyl-2-thiohydantoins (VIII–XIV), ranges of 1445–1430 and 1250–1230 cm<sup>-1</sup> were found for  $\nu_{as}$  and  $\nu_s$  NCS, respectively. 2-Thiohydantoins (XVII–XIX) showed the  $\nu_{as}$  NCS mode centered at 1445 cm<sup>-1</sup> and the  $\nu_s$  NCS mode at 1220 cm<sup>-1</sup>. 1-Acetyl-2-thiohydantoins (XV and XVI), which are structurally related to 2-thiobarbiturates, had bands at 1410 and 1210 cm<sup>-1</sup> (Table II). 2-Thiobarbiturates (XX–XXIV) (Table III) showed bands at 1425–1410 and 1225–1200 cm<sup>-1</sup>, in good agreement with 1-acetyl-2-thiohydantoins (XV and XVI) (Table II).

In 2,4-dithiobarbital (XXVI) and 2,4,6-trithiobarbital (XXVIII),

the position of characteristic bands of the 2-thiocarbonyl group seemed to be rather independent and showed only slight deviations, which probably arose from electronic density modifications in the barbiturate nucleus by introducing a second and a third thiocarbonyl group. In 4-thiobarbital (XXV) and 2,4-dithiobarbital (XXVI), the values of 1455/1248 and 1448/1240 cm<sup>-2</sup> were somewhat higher than the observed range for 2-thiobarbiturates; this fact is in agreement with the “more thioamide character” of the 4-thiocarbonyl group (Table III).

In the thiobarbiturate series, coupling between the 4- and 6-thiocarbonyl groups can be expected, as was demonstrated in the barbiturate series (2). In this type of coupling, the vibrators are not directly linked; in consequence, the higher characteristic frequency is assigned to  $\nu_s$ . Owing to the coupling strength (about 200 cm<sup>-1</sup>) and the symmetry of the barbiturate nucleus, the NCS antisymmetric and symmetric stretching modes of the 4- and 6-thiocarbonyl groups are coupled two by two; four signals result, two around 1400 cm<sup>-1</sup> and two around 1200 cm<sup>-1</sup>. This prediction agrees with the observed values (Table III).

The use of  $\nu_{as}$  and  $\nu_s$  NCS completes the characterization by the thioureide band. Whereas the phenyl nucleus bands around 1600 and 1500 cm<sup>-1</sup> are generally of moderate absorption, the thioureide band can be easily located as a strong band in *N*-phenylthioureas (I–VII) at 1555–1515, in 3-phenyl-2-thiohydantoins (VIII–XIV) at 1520–1485, in 2-thiohydantoins (XVII–XIX) at 1530–1512, and in 1-acetyl-2-thiohydantoins (XV and XVI) at 1470 cm<sup>-1</sup>. 2-Thiobarbiturates (XX–XXIV), 2,4-dithiobarbital (XXVI), and 2,4,6-trithiobarbital (XXVIII) present thioureide bands at 1545–1510 cm<sup>-1</sup>. Figure 1 shows one representative IR spectrum of this series of compounds.

4-Thiobarbital (XXV) and 4,6-dithiobarbital (XXVII) do not show thioureide bands. This fact reflects the “more thioamide character” of the 4-thiocarbonyl group in agreement with above results. Bands were found at 1480 cm<sup>-1</sup> for XXV and at 1460 cm<sup>-1</sup> for XXVII in the observed range for *N*-acetylthioamides (13).

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<sup>5</sup> Thyreosedine, Kela.

<sup>6</sup> Pentothal, Abbott.

<sup>7</sup> Inactin, Promonta.

<sup>8</sup> Thionarcex, Crinex Uve.

<sup>9</sup> Kemithal, Imperial Chemical.

<sup>10</sup> In this appellation, C and D bands can be regarded as the antisymmetric and symmetric stretching modes of NCS, respectively.