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# Rotational Barriers of the Carbon-Nitrogen Bond in Hydroxy and Methoxy Substituted Aromatic Thioamides. Influence of Hydrogen Bonding

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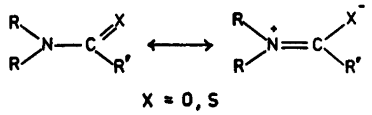
The barrier to rotation around the C—N bond in *o*- and *p*-hydroxy and methoxy substituted *N*,*N*-dimethylthiobenzamides and thionaphthamides has been studied by the NMR technique. It was found that *o*-hydroxy substitution decreases the barrier ($\Delta G^{\ddagger}$) by 10—20 kJ/mol and *o*-methoxy substitution increases the barrier by 10—20 kJ/mol. NMR, IR and UV data were used to elucidate the strength of hydrogen bonding and the conformational situation. Comparatively weak intramolecular hydrogen bonds were found in the *o*-hydroxy derivatives due to a sterically induced twist around the Ar—C(S) bond. In the transition state for the rotation the molecule is free from steric strain and a stronger hydrogen bond in this state is suggested as an important contribution to the barrier-lowering effect of *o*-hydroxy substitution. No significant effect of intermolecular hydrogen bonding on the barrier in the *p*-hydroxy derivatives was observed. Comparison is made with the analogous dithioesters.

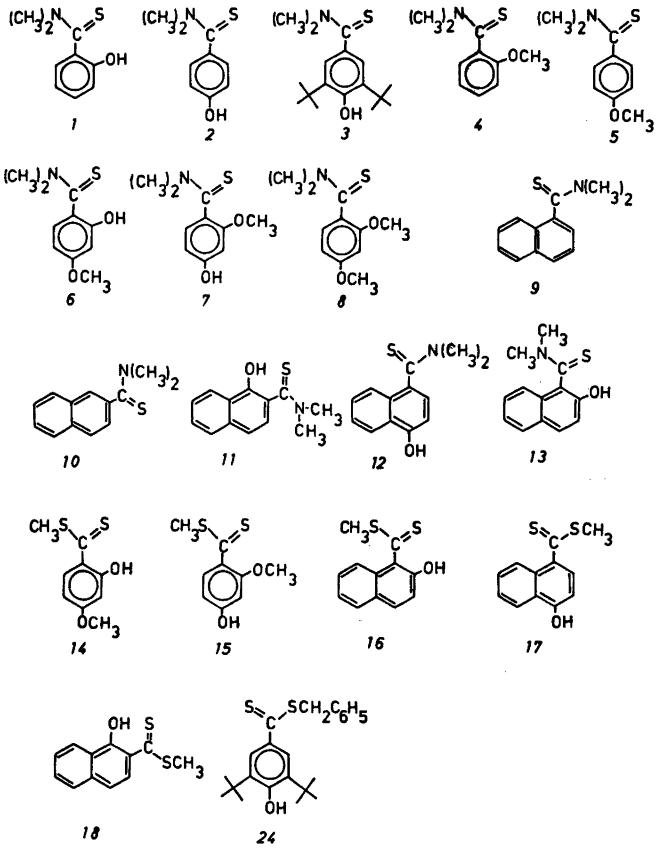
Amides and thioamides have been extensively studied in order to obtain information about the barrier to internal rotation around the carbon-nitrogen bond.[1] In all likelyhood this barrier is associated with the partial double bond character of the C—N bond. The barrier to thioamide rotation in *N*,*N*-dimethylthiobenzamide is 77.0 kJ/mol [2] which is about 25 kJ/mol lower than the barrier in dimethylthioformamide.[3] The observed lowering of the barrier has been attributed to electronic effects; competitive conjugation is believed to decrease the transition state energy more than the ground state energy. The same trend is observed in the analogous amide systems. The effect of *meta* and *para* substitution in *N*,*N*-dimethylbenzamides correlates well with Hammett's $\sigma$ or, better, $\sigma^+$ constants with $\varrho$ values of +1.6 and +1.1, respectively.[4]




*Scheme 1.*

Introduction of an *ortho* substituent in benzamides usually produces a noticeable effect on the barrier. The substituents Cl, $NO_2$, Me, and MeO all cause an increase in barrier height in *N*,*N*-dibenzylbenzamide.[5] Thus, the barrier seems to be determined primarily by the steric demands of an *ortho* substituent, presumably through inhibition of resonance between the ring and the carbonyl group in the transition state.

The barrier in *o*-hydroxy- and *o*-amino-*N*,*N*-dialkylbenzamides is dramatically lower than those of normal *ortho*-substituted *N*,*N*-dialkylbenzamides.[4—6] This reduction has been attributed to enhanced conjugative stabilization of the transition state due to intramolecular hydrogen bonding [4] and to the existence of a "quasiaromatic chelated ring" created by the hydrogen bond leading to a decrease in C—N bond order.[6] In view of the steric strain in the planar molecule, it seems doubtful whether an optimal O···H—O arrangement for hydrogen bonding, required by the latter proposal, is possible. Furthermore, the barrier increases in solvents which may enter into intermolecular hydrogen bonding to the amide.



*Scheme 2.*

In our opinion further experimental studies are necessary before the observed barrier-lowering effect of *o*-hydroxy and *o*-amino substituents can be understood.

This paper reports a study of the effects of hydroxy and methoxy substitution in the *ortho* and *para* positions in *N*,*N*-dimethylthiobenzamides and *N*,*N*-dimethylthionaphthamides on the torsional barrier around the C–N bond. Special attention has been devoted to the effects of inter- and intramolecular hydrogen bonding and of steric interference. The compounds studied are presented in Scheme 2.

## RESULTS

*Barrier measurements.* The free energy of activation at the coalescence for the thioamides and the thionaphthamides are summarized in Table 1. As the coalescence temperatures range from −16 to +186 °C and an attempt has been made to use the same solvent for all compounds, the number of available solvents is highly reduced. With two exceptions, all spectra were recorded in *o*-dichlorobenzene (ODC). The low solubility of *2* in ODC made it necessary to use dimethyl sulfoxide (DMSO) instead. Some of the compounds were studied in several solvents. No significant difference in $\Delta G^{\ddagger}$ was obtained for the *para*-hydroxy derivatives in ODC and DMSO, despite the capacity of the latter solvent to form strong hydrogen bonds with phenols.[7] On the other hand, a drastic increase of the barrier was observed for *N*,*N*-dimethyl-2-hydroxy-4-methoxythiobenzamide in pyridine-$d_5$, indicating that this solvent is able to form strong hydrogen bonds to the solute.

*Table 1.* Coalescence data for *N,N*-dimethylthiobenzamides and *N,N*-dimethylthionaphthamides.

| Compound | Solvent | $\delta\nu$/Hz[a] | $T_c$/K | $\Delta G^{\ddagger}_c$/kJ mol$^{-1}$ |
|---|---|---|---|---|
| *1* | ODC | 25.5 | 302.5 | 64.0 |
| *2* | $(CD_3)_2SO$ | 19.4 | 343.6 | 73.6 |
| *3* | ODC | 24.4 | 331.1 | 70.3 |
| *4* | ODC | 32.3 | 440.0 | 93.7 |
| *5* | ODC | 26.2 | 335.3 | 71.1 |
| *6* | $CDCl_3$ | 13.9 | 258.7 | 55.6 |
| | pyridine-$d_5$ | 19.0 | 298.1 | 63.6 |
| *7* | ODC | 31.3 | 431.2 | 91.6 |
| | $(CD_3)_2SO$ | 27.4 | 428.9 | 91.6 |
| *8* | ODC | 30.6 | 419.5 | 89.1 |
| *9* | ODC | 51.5 | 458.9 | 95.8 |
| *10* | ODC | 34.2 | 358.7 | 75.3 |
| *11* | ODC + $C_6H_5F$ | 26.8 | 258.1 | 54.0 |
| | $CDCl_3$ | 21.3 | 256.7 | 54.4 |
| *12* | ODC | 48.4 | 441.0 | 92.5 |
| | $(CD_3)_2SO$ | 41.2 | 438.7 | 92.5 |
| *13* | ODC | 48.5 | 405.6 | 84.5 |

[a] At 60 MHz.

*Table 2.* Thermodynamic parameters for *6* and *11* from the complete lineshape analyses.

| Compound | Solvent | $\Delta G^{\ddagger}_{298}$/kJ mol$^{-1}$ | $\Delta H^{\ddagger}$/kJ mol$^{-1}$ | $\Delta S^{\ddagger}$/J mol$^{-1}$ K$^{-1}$ |
|---|---|---|---|---|
| *6* | ODC + $C_6H_5F$ (3:1) | 55.6 | $57 \pm 2$[a] | $4 \pm 8$ |
| *11* | $CDCl_3$ | 54.4 | $51 \pm 1$ | $-10 \pm 2$ |

[a] The errors are standard deviations from a least-squares plot.

*Table 3.* IR and NMR data on hydrogen bonding.

| Compound | IR[a] | | | NMR[b] |
|---|---|---|---|---|
| | $\nu_{OH}$(free)/cm$^{-1}$ | $\nu_{OH}$(complexed)/cm$^{-1}$ | $\Delta\nu_{OH}$/cm$^{-1}$ | $\delta$ |
| *1* | 3590 | 3250 | 340 | 7.20 |
| *3* | 3630 | – | – | 5.25 |
| *6* | 3590 | 3140 | 450 | 9.20 |
| *7* | 3590 | 3200 | 390 | 8.30 |
| *11* | 3580 | 3130 | 450 | 9.42 |
| *13* | 3585 | 3310 | 275 | 7.20 |
| *14* | – | 2880 | (700)[c] | 12.83 |
| *15* | 3580[d] | 3360[d] | 220 | 6.50 |
| *16* | 3585 | 3455 | 130 | 6.62 |
| *17* | – | – | – | 5.85 |
| *18* | – | 2650 | (930)[c] | 14.20 |
| *24* | – | – | – | 5.83 |

[a] 5 % in $CDCl_3$. Cell thickness = 0.1 mm. [b] *Ca.* 10 % in $CDCl_3$. [c] With a value of 3580 cm$^{-1}$ for $\nu_{OH}$(free). [d] Saturated solution (*ca.* 3 %).

A complete lineshape analysis for the *N*-methyl signals was performed for two compounds, *6* and *11*. These two compounds show barriers much lower than those of ordinary aromatic *N*,*N*-dimethylthioamides. The methoxy signal in *6* and TMS for *11* were used as reference signals for determination of $T_2$. The results from the complete lineshape analyses are summarized in Table 2.

*IR and NMR data on hydrogen bonding.* An important factor in the understanding of the low barriers of the *o*-hydroxy-*N*,*N*-dimethylthiobenzamides is the strength of hydrogen bonds in these compounds. Likewise, hydrogen bonding in the *p*-hydroxy-*N*,*N*-dimethylthiobenzamides can affect their barriers.

IR data on hydrogen bonding for *o*- and *p*-hydroxythiobenzamides and -thionaphthamides are shown in Table 3. In addition, the table contains data for four analogous dithioesters.

The concentration dependence of the intensity ratio between the bands of free and associated forms was also studied. The *p*-hydroxy substituted derivatives, except *3*, showed a concentration dependence typical for intermolecularly hydrogen bonded systems. Upon dilution, the relative intensity of the sharp band assigned to unassociated OH-stretching band increased at the expense of the intensity of the broad band at lower frequency assigned to the associated form. On the other hand, the *o*-hydroxy substituted derivatives exhibited no concentration dependence. One exception was *13*, which showed a concentration dependence of the intensity ratio.

Although there is a large number of contributions to the $^1$H NMR chemical shift change accompanying interactions such as hydrogen bonding, and although it is unlikely that the hydrogen bonding contribution can be separated from the other terms, the position of the hydroxy proton chemical shifts has been found to be linearly related to $-\Delta H$, the enthalpy of the hydrogen-bonding interaction, in a series of 30 phenol-base systems.[7] The chemical shifts for the hydroxy protons of the thioamides and the corresponding dithioesters in about 10 % deuteriochloroform solution are summarized in Table 3. Fig. 1 shows a plot of $\Delta\nu_{OH}$ against $\delta_{OH}$. A good correlation is obtained including intra- as well as intermolecularly hydrogen-bonded compounds.

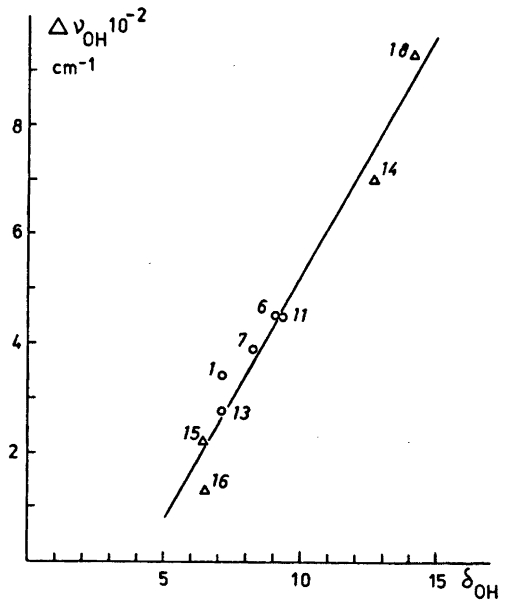



*Fig. 1.* Infrared $\Delta\nu_{OH}$ *versus* NMR chemical shifts for the phenolic protons in $CDCl_3$ solutions. (△ = dithioesters, ○ = thioamides).

The IR and NMR results make it possible to estimate the strength of the hydrogen bond and to determine whether the compounds in question are intra- or intermolecularly hydrogen bonded. Thus, the two dithioesters *14* and *18* are obviously intramolecularly hydrogen bonded by strong bonds. The analogous thioamides *6* and *11* and compound *1* are likewise intramolecularly hydrogen bonded *but with much weaker bonds.*

Both the dithioesters and the thioamides with a hydroxy group in the *para* position are intermolecularly hydrogen bonded, *but the bonds are stronger in the thioamide series than in the dithioester series*, in contrast to the *o*-hydroxy derivatives.

*UV measurements.* The UV spectra of the thioamides and of some of the corresponding dithioesters are listed in Table 4. The spectra were recorded in heptane containing up to 10 % of dichloromethane for solubility reasons.

## DISCUSSION

*Rotational barriers.* Certain generalizations emerge from the results of the barrier measurements:

*Table 4.* Ultraviolet spectra of thioamides and dithioesters in heptane containing 0.5 % $CH_2Cl_2$ if not otherwise stated.

| Compound | $\lambda_{max}$/nm | log $\varepsilon$ | $\lambda_{max}$/nm | log $\varepsilon$ | $\lambda_{max}$/nm | log $\varepsilon$ |
|---|---|---|---|---|---|---|
| *N,N*-Dimethylthiobenzamide [a] | 395 | 2.50 | 282 | 3.93 | 250 | 3.95 |
| *N*-Methyl-1,2,3,4-tetrahydro-isoquinoline-1-thione [b] | 425 | 2.09 | 323 | 3.81 | 299 | 3.71 |
| *1* | 377[c] | 2.90 | 290 | 4.01 | 242 | 3.91 |
| *4* | 379[c] | 2.48 | 281 | 4.03 | 245 | 3.93 |
| *5* | 389[c] | 2.73 | 276 | 4.16 | 253 | 4.18 |
| *2* | 383[c] | 2.75 | 276 | 4.13 | 259 | 4.06 |
| *6* | 370[c] | 3.16 | 288 | 4.04 | 279 | 4.04 |
| *8* | 378[c] | 2.75 | 283 | 4.11 | 255 | 4.09 |
| *9* | 379[c] | 2.58 | 304[d] | 3.89 | 275 | 4.13 |
| *10* | 384[c] | 2.84 | 295[d] | 4.03 | 285.5 | 4.13 |
| | | | | | 275 | 4.11 |
| *13* | 382[c] | 3.07 | 334 | 3.56 | 285 | 4.06 |
| *11* | 373[c] | 3.46 | 346 | 3.49 | 289[d] | 4.13 |
| | | | | | 277.5 | 4.21 |
| *14* | 450[c,d] | 2.53 | 381 | 4.26 | 324 | 4.21 |
| *15* | 486[c] | 2.30 | | | 325 | 4.12 |
| *18* | 439 | 4.04 | 422 | 4.06 | 330 | 4.37 |
| *16* | 478[c,d] | 2.46 | 401 | 3.08 | 328 | 3.85 |

[a] Ref. 9, in heptane. [b] Ref. 35, in heptane. [c] In heptane + 10 % $CH_2Cl_2$. [d] Shoulder.

(1) Introduction of a methoxy group in the *ortho* position of a *N,N*-dimethylthiobenzamide raises the barrier by 10 – 20 kJ.

(2) Introduction of a hydroxy group in the *ortho* position lowers the barrier by 10 – 20 kJ.

(3) Introduction of a hydroxy or a methoxy group in the *para* position lowers the barrier by 2 – 9 kJ.

(4) The barrier in *N,N*-dimethyl-1-thionaphthamide is *ca.* 20 kJ higher than in the 2-substituted isomer.

(5) The influence of the solvent is small, except for the *ortho*-hydroxy substituted derivatives in basic solvents such as pyridine, in which the intramolecular hydrogen bond is broken.

It is known that the angle between the thioamide plane and the aromatic ring in *N,N*-dimethylthiobenzamide is *ca.* 40°,[8–11] indicating that steric interaction in the planar form is considerable. Steric interference between the *E*-methyl group and the *ortho* hydrogen prevents a coplanar conformation around the Ph – C(S) bond. In the transition state for the rotation, the interfering methyl group is twisted out of the region in which steric interaction can be expected. The rotation can thus be coupled with a decrease of the angle around the Ph – C(S) bond, resulting in more effective conjugation between the thiocarbonyl group and the benzene ring with accompanying gain in delocalization energy. Moreover, this energy gain is larger in the transition state than in the initial state, since in the transition state the cross conjugation with the dimethylamino group is inhibited. The $\pi$-barrier accompanying rotation around the benzene-thiocarbonyl bond is also affected by substitution in the ring. This effect will change the energy of the transition state relative to that of the initial state. In the *ortho*-methoxy derivatives and in the $\alpha$-thionaphthamides, the thiocarbonyl group is kept out of the plane in the transition state as well, which increases its energy, with a higher barrier as a consequence.

It has been clearly demonstrated that amides and thioamides coordinate with the oxygen and sulfur atoms on hydrogen bonding to protic species. The torsional barriers of such compounds are expected to be higher in protic solvents than in other solutions. Hydrogen bonding may stabilize the polar structure represented by the charge-separated resonance

notation and thus increase the double bond character of the C–N bond. This has been found to be the case for amides dissolved in protic solvents (*e.g.*, water [12] and formamide[13]).

The effect of added phenol on the rate of rotation around the C–N bond in *N*-benzyl-*N*-methyl-2-chlorobenzamide and its thio analogue in ODC has been studied by Siddall *et al.*[14] They found that $\Delta G^{\ddagger}$ increased with phenol concentration, whereas $\Delta S^{\ddagger}$ never deviated significantly from zero. The effect of phenol on the thioamide barrier was, however, much less marked than on the amide barrier and close to the experimental error. This lesser tendency of the thioamide barriers to be affected by protic solvents is consistent with the weaker association of thioamides with such species.[15]

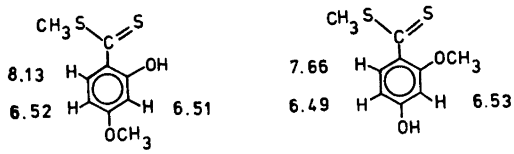
Instead of raising the barrier, introduction of an *ortho*-hydroxy group has the opposite effect, and it is obvious that we must seek another model for the rotational process in these systems.

In the *ortho*-hydroxythiobenzamide derivatives, a moderately strong intramolecular hydrogen bond was experimentally verified. The strength of this bond is dependent on the dihedral angle between the amino group and the thiocarbonyl group ($\theta$) as well as the dihedral angle between the phenyl ring and the thiocarbonyl group ($\phi$). According to the simple electrostatic model of the hydrogen bond, maximum strength of the bond is obtained with a planar thioamide since then the negative charge on the sulfur atom is largest.

The energy of the hydrogen bond depends also on the distance between the sulfur and oxygen atoms, and thus on the angle $\phi$, the ideal distance for hydrogen bonding being the situation where this angle is zero or near zero.

Due to the steric interference discussed above, both the angles $\theta$ and $\phi$ cannot be zero simultaneously. If the sulfur atom is forced nearer the plane of the ring owing to hydrogen bonding, the dimethylamino group has to be twisted or pyramidalized. However, it seems unlikely that the sulfur atom lies in the phenyl plane in the *ortho*-hydroxy derivatives for the following reasons.

Firstly, it has been observed that in secondary *ortho*-hydroxythiobenzamides, where the single substituent on nitrogen is in the *Z* position and consequently the sulfur atom may lie in the plane, the NMR signal of the *ortho* hydrogen is shifted 0.5–1 ppm to lower field compared to the signals of the other aromatic protons.[16] Such a downfield shift is not observed in *N*,*N*-dimethylthiobenzamide nor in the *ortho*-hydroxy derivatives. A comparison with the dithioesters *14* and *15* is interesting. A strongly deshielding region in the plane of the dithioester function makes the *ortho* hydrogen shift to lower field if the sulfur atom lies in the plane of the ring. The hydrogen atom moves out of the deshielding region if the thiocarbonyl group is forced out of the plane as in *15*.




*14* *15*

*Scheme 3.*

The fact that the ring hydrogen atom in the *ortho* position in *ortho*-hydroxy substituted *N*,*N*-dimethylthiobenzamides is not shifted downfield compared to the methoxy analogue supports the suggestion that the sulfur atom does not lie in the benzene plane.

Secondly, the distance between the sulfur and oxygen atoms becomes greater when the thiocarbonyl group is twisted, which is consistent with the observed weaker hydrogen bonds in the *ortho*-hydroxy compounds compared to those in the corresponding dithioesters.

Thirdly, the UV spectra (*vide infra*) of these compounds are perfectly consistent with the hypothesis that the *ortho*-hydroxy derivatives are twisted around both the Ph–C(S) and the C(S)–N bonds.

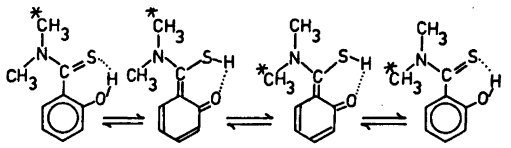
Thus, in the initial state for the rotation both the angles $\theta$ and $\phi$ are larger than zero. The magnitudes of these angles are determined by the maximum energy gain obtained by resonance and hydrogen bonding, balanced by the steric interaction between the *E*-methyl and the *ortho* hydrogen. The overall result must be a lower energy compared to a situation with no hydrogen bond.

In the transition state, the sulfur atom can move still nearer the ideal distance for hydro-

gen bonding, that is in the plane of the ring. Though the electronic conditions for hydrogen bonding are more favourable in the planar thioamide this may be more than balanced by the better steric conditions in the transition state. It is believed that an important contribution to the barrier lowering effect of an *ortho*-hydroxy group is a stronger hydrogen bond in the transition state than in the initial state.

An examination of the effect of *para*-methoxy substitution in unsubstituted [2] and *ortho*-hydroxy substituted *N,N*-dimethylthiobenzamide reveals that an enhanced conjugative stabilization of the transition state also plays an important role in the barrier lowering effect of an *ortho*-hydroxy group.

Another mechanism for the rotational process that cannot be ruled out involves a rapid tautomeric equilibrium prior to the rotation.

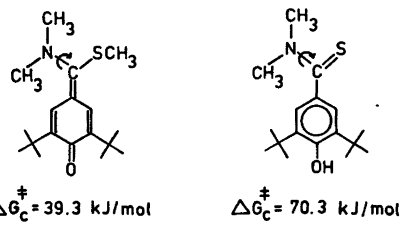


*Scheme 4.*

If the first step is fast and reversible, the observed rate constant for the rotation is a weighted mean value between those for rotation of the thioamide and of the quinone methide forms:

$$k_{obs} = pk_{thioamide} + (1-p)k_{quinone\ methide}$$

where $p$ = mol fraction of thioamide. The tautomeric equilibrium must be in favour of the thioamide, since no evidence (UV, IR and NMR) for the existence of the quinone methide has been obtained. However, this does not preclude the possibility of the existence of a




*Scheme 5.*

kinetically significant concentration of the quinoid form. We found a much lower barrier to C–N rotation in a quinone methide compared to that of the corresponding thioamide in an analogous *para*-substituted system.

*Entropy of activation.* In the preceding discussion the free energies of activation of many compounds have been compared despite the fact that they are measured at very different temperatures. This is of course only meaningful if the entropy of activation ($\Delta S^{\ddagger}$) is close to zero. Fortunately, numerous studies on *tert* amides and thioamides appear to confirm this assumption.[17–27]

In their study on the effect on the activation parameters of added phenol, Siddall *et al.* found that $\Delta S^{\ddagger}$ is never significantly different from zero although $\Delta G^{\ddagger}$ increased with phenol concentration.[14]

The model for the rotational process suggested above involves intramolecular hydrogen bonds in the initial state as well as in the transition state for the *ortho*-hydroxy substituted thiobenzamides. Consequently, no marked change in the intermolecular interactions is to be expected during the course of the rotation.

The entropies of activation for *6* and *11* were measured to $+4 \pm 8$ and $-10 \pm 2$ J/mol K, respectively. These results are in harmony with the expected small change in order in the solution during the rotation.

*Ultraviolet spectra.* The ultraviolet spectra of thiones, such as thioamides and dithioesters, contain a characteristic long-wavelength, low-intensity band and more intense bands at shorter wavelengths. It has been shown that the former band is due to the excitation of a nonbonding electron from the sulfur atom to an antibonding $\pi$ orbital, an $n \rightarrow \pi^*$ transition.[28–31].

Hydrogen bonding usually causes significant perturbations of the electronic transitions of the system, and the most commonly observed effect is the blue shift of the $n \rightarrow \pi^*$ transition[32–34] whereas the shift in the $\pi \rightarrow \pi^*$ transition can be either towards the blue or towards the red, depending on the change in polarity on excitation.

Comparing the two hydrogen bonded, *ortho*-hydroxy substituted derivatives *1* and *6* with the two *ortho*-methoxy analogs *4* and *8*, one finds that the $n \rightarrow \pi^*$ band appears at shorter

wavelength in the hydrogen bonded species but that the shifts are small, 2 and 8 nm.

It has been shown that successive *N*-methylation of thiobenzamide causes hypsochromic shifts of the $\pi\rightarrow\pi^*$ and $n\rightarrow\pi^*$ bands due to a departure from coplanarity caused by interference between the methyl group and the ring hydrogen atoms.[6] According to this observation, the $\pi\rightarrow\pi^*$ bands of *1* and *6* would be expected to appear at longer wavelength than in *4* and *8*, respectively, due to the decrease of the angle around the Ar–C(S) bond upon hydrogen bonding. This is what was observed, but the shifts are again small, 9 and 5 nm. This observation is in line with the hypothesis that the *ortho*-hydroxy derivatives are twisted around the Ar–C(S) bond. A coplanar arrangement around this bond would make the red shift much more pronounced.

It is interesting to make a comparison with the two dithioesters *14* and *15*. In *14* there is no steric interaction between the *S*-methyl group and the ring hydrogen atoms so that the molecule can adopt a planar, strongly hydrogen bonded form. Thus, $\pi\rightarrow\pi^*$ band of *14* is split into a doublet, the long wavelength part of which is shifted 57 nm towards longer wavelength compared to the short wavelength part, while the other remains close to the position of the single band in *15*. A similar splitting of this band was also found in *N*-methyl-1,2,3,4-tetrahydroisoquinoline-1-thione, where coplanarity is enforced by ringclosure.[35]

Furthermore, the $n\rightarrow\pi^*$ band of *14* is shifted 36 nm towards shorter wavelengths compared to that in *15*, in agreement with the normal behaviour of $n\rightarrow\pi^*$ bands upon hydrogen bonding.

Sandström observed an increase in oscillator strength of the $n\rightarrow\pi^*$ band on going from thiobenzamide to *N*,*N*-dimethylthiobenzamide,[9] and ascribed this to the increasing departure from coplanarity between the thioamide group and the benzene ring, which causes an increased mixing of the $n\rightarrow\pi^*$ and $\pi\rightarrow\pi^*$ transitions. Large oscillator strengths were found for the thioamides studied in this investigation as well, but the effect is much more pronounced for the *ortho*-hydroxy derivatives (Table 5). This enhanced effect can be understood in view of a departure from coplanarity in the thioamide group. The lone pair orbitals on the sulfur atom can now mix with the *p* orbital on the nitrogen atom since these orbitals are no longer orthogonal.

*Table 5.* Oscillator strengths for the $n\rightarrow\pi^*$ transition in some thiobenzamides.

| Compound | Oscillator strength |
|---|---|
| Thiobenzamide | 0.0035 |
| *N*,*N*-Dimethylthiobenzamide | 0.0046 |
| *1* | 0.011 |
| *6* | 0.021 |

The oscillator strengths have been calculated with the aid of the formula

$$f = 4.31 \times 10^{-9} \times \varepsilon_{max} \times 2(\nu_{max} - \nu_{0.5})$$

where $\nu_{0.5}$ is the wave number on the low frequency side of the band at which the extinction has decreased to half of the maximum value.

## EXPERIMENTAL

The NMR spectra were recorded on a Varian A-60 or Varian A-60 A spectrometer equipped with Varian V-6031 variable temperature probe and V-6040 temperature controllers. Chemical shifts were measured by the side-band technique using an HP 200 CD Audio Oscillator. The frequencies were measured with an HP 3734 Electronic Counter. The shifts are given downfield from TMS. The evaluation of rate constants and the measurement of temperature and $T_2$ were performed as previously described.[36] IR spectra were recorded on a Perkin-Elmer Model 221 prism-grating instrument and UV spectra on a Unicam SP 800 B Ultraviolet Spectrometer.

*Preparations.* I. Gompper *et al.* have synthesized a number of dithiocarbonic acids and esters from phenols and carbon disulfide in a manner analogous to the Kolbe salicylic acid synthesis.[37] The hydroxyaryl dithioesters were synthesized by this procedure (I*a* corresponds to "Verfahren" A or B, I*b* to "Verfahren" C or D in Ref. 37).

The *N*,*N*-dimethyl-hydroxyaryl thioamides were prepared by either of four different methods:

II. The corresponding ethoxycarbonylmethyl hydroxyaryl dithioester was allowed to react with 2 equiv. of dimethylamine in boiling benzene solution for 2–3 h. The solution was evaporated and the residue recrystallized,

when necessary after prior column chromatography.

III. This method is a variant of the Willgerodt-Kindler reaction.[38] An aromatic hydroxyaldehyde (*e.g.* salicylic aldehyde) was mixed with 1.5 equiv. of sulfur and heated to 120 °C in an oil bath. Dimethylamine was slowly bubbled through the mixture for 1 – 3 h. The still warm, thick oil was poured onto ice-water. The solution was neutralized with hydrochloric acid and extracted with chloroform. The organic phase was dried over $MgSO_4$, followed by evaporation. The residue was chromatographed on an aluminia or silica column and recrystallized. (From salicylic aldehyde 2-hydroxy-*N,N*-dimethylthiobenzamide was formed).

IV. Viola *et al.* have found that *N,N*-dimethylcarbamyl chloride reacts with activated aromatic compounds in the presence of Friedel-Crafts catalysts to give *N,N*-dimethyl thioamides.[39]

V. Aromatic thioamides, not containing hydroxy groups, were prepared by thionation of the corresponding amide with phosphorus pentasulfide.

The following compounds were described previously: *8*,[39] *14*,[37] *16*.[37]

*Methyl 4-hydroxy-2-methoxydithiobenzoate* (*15*) was prepared from resorcinol monomethylether by method I*b*. Recryst. from benzene-ligroin (3:2); yield 38 %, m.p. 126.5 – 128 °C. Anal. found: C 49.7; H 4.58; S 29.9. Calc. for $C_9H_{10}O_2S_2$: C 50.4; H 4.71; S 29.9.

*Methyl 4-hydroxy-1-dithionaphthoate* (*17*) and *methyl 1-hydroxy-2-dithionaphthoate* (*18*) were prepared from 1-naphthol by method I*b*. The two isomers were separated by chromatography on a silica column (benzene-ether). *17* was recrystallized from benzene-ligroin (1:2). Yield 19 %, m.p. 113 – 114 °C. *18* was recrystallized from benzene-ligroin (1:3). Yield 12 %, m.p. 75 – 77 % °C. Anal. $C_{12}H_{10}OS_2$: C, H, S.

*Ethoxycarbonylmethyl 4-hydroxy-2-methoxydithiobenzoate* (*19*) was prepared from resorcinol monomethylether by method I*b*. Recryst. from benzene-ligroin (1:1); yield 18 %, m.p. 106 – 107 °C. Anal. found: C 50.8; H 4.97; S 22.3. Calc. for $C_{12}H_{14}O_4S_2$: C 50.3; H 4.92; S 22.4.

*Ethoxycarbonylmethyl 2-hydroxy-1-dithionaphthoate* (*20*) was prepared from 2-naphthol by method I*a*. Recryst. from 90 % methanol; yield 25 %, m.p. 117.5 – 118.5 °C. Anal. $C_{15}H_{14}S_2O_3$: C, H, S.

*Ethoxycarbonylmethyl 4-hydroxy-1-dithionaphthoate* (*21*) and *ethoxycarbonylmethyl 1-hydroxy-2-dithionaphthoate* (*22*) were prepared from 1-naphthol by method I*b*. The isomers were separated on an alumina column (benzene-ether). *21* was recrystallized from ethanol; yield 27 %, m.p. 118.5 – 119.5 °C. *22* was recrystallized from ligroin; yield 4 %, m.p. 69 – 70.5 °C. Anal. $C_{15}H_{14}O_3S_2$: C, H. S.

*Ethoxycarbonylmethyl 3,5-di*-tert-*butyl-4-hydroxydithiobenzoate* (*23*) was prepared from 2,6-di-*tert*-butylphenol by method I*a*. Recryst. from 90 % ethanol; yield 61 %, m.p. 101 – 102 °C. Anal. $C_{19}H_{28}O_3S_2$: C, H, S.

*Benzyl 3,5-di*-tert-*butyl-4-hydroxydithiobenzoate* (*24*) was prepared from 2,6-di-*tert*-butylphenol by method I*a*. Recryst. from ethanol; yield 57 %, m.p. 120 – 121.5 °C. Anal. found: C 70.3; H 7.44; S 17.4. Calc. for $C_{22}H_{28}OS_2$: C 70.9; H 7.57; S 17.2.

*2-Hydroxy*-N,N-*dimethylthiobenzamide* (*1*) was prepared from salicylic aldehyde by method III. Recryst. from benzene-ligroin (2:5); yield 53 %, m.p. 65 – 67 °C. Anal. $C_9H_{11}NOS$: C, H, N, S.

*4-Hydroxy*-N,N-*dimethylthiobenzamide* (*2*) was prepared from *p*-hydroxybenzaldehyde by method III. Recryst. from 80 % ethanol; yield 22 %, m.p. 166 – 168 °C. Anal. $C_9H_{11}NOS$: C, H, N, S.

*3,5-Di*-tert-*butyl-4-hydroxy*-N,N-*dimethylthiobenzamide* (*3*) was prepared from *23* by method II. Recryst. from ethanol; yield 86 %, m.p. 163 – 164 °C, lit.value:[40] 163.5 – 164.5 °C.

*4-Hydroxy-2-methoxy*-N,N-*dimethylthiobenzamide* (*7*) was prepared by two methods. A. From *19* by method II. Recryst. from 70 % ethanol; yield 54 %, m.p. 143 – 144 °C. B. From resorcinol monomethylether by method IV. Recryst. from 70 % ethanol; yield 45 %, m.p. 144 – 145 °C. Anal. $C_{10}H_{13}NO_3S$: C, H, N, S.

*2-Hydroxy-4-methoxy*-N,N-*dimethylthiobenzamide* (*6*) was prepared from 2-hydroxy-4-methoxybenzaldehyde by method III. Recryst. from benzene-ligroin (2:3); yield 34 %, m.p. 79 – 80 °C. Anal. $C_{10}H_{13}NO_2S$: C, H, N, S.

*2-Methoxy*-N,N-*dimethylthiobenzamide* (*4*) was prepared from 2-methoxy-*N,N*-dimethylbenzamide by method V. The product was distilled in *vacuo*, b.p. 145 – 155 °C/0.07 kPa; yield 57 %. Anal. found: C 60.9; H 6.58; N 7.05; S 16.6. Calc. for $C_{10}H_{13}NOS$: C 61.5; H 6.71; N 7.17; S 16.4.

*2-Hydroxy*-N,N-*dimethyl-1-thionaphthamide* (*13*) was prepared from *20* by method II. Recryst. from 90 % ethanol or benzene-ligroin (1:2); yield 58 %, m.p. 146 – 147 °C. Anal. $C_{13}H_{13}NOS$: C, H, N, S.

*1-Hydroxy*-N,N-*dimethyl-2-thionaphthamide* (*11*) was prepared from *22* by method II. Recryst. from ethanol; yield 52 %, m.p. 84 – 85 °C. Anal. found: C 68.0; H 5.84; N 5.98; S 14.1. Calc. for $C_{13}H_{13}NOS$: C 67.5; H 5.66; N 6.05; S 14.1.

*4-Hydroxy*-N,N-*dimethyl-1-thionaphthamide* (*12*) was prepared from *21* by method II. Recryst. from benzene, yield 66 %, m.p. 168 – 170 °C. Anal. $C_{13}H_{13}NOS$: C, H, N, S.

N,N-*Dimethyl-1-thionaphthamide* (*9*) was prepared from *N,N*-dimethyl-1-naphthamide by method V. Recryst. from 90 % ethanol; yield 40 %, m.p. 68.5 – 70 °C. Anal. $C_{13}H_{13}NS$: C, H, N, S.

N,N-*Dimethyl-2-thionaphthamide* (*10*) was prepared from *N,N*-dimethyl-1-naphthamide by method V. Recryst. from 90 % ethanol;

yield 21 %, m.p. 97–98 °C. Anal. $C_{13}H_{13}NS$: C, H, N, S.

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