ml. of 35% HCl was refluxed for 70 hr., then 0.7 ml. of 35% HCl was added and again refluxed for 24 hr. The reaction mixture was then poured into H_2O and enxtracted with Et_2O. From the Et_2O solution 50 mg. of yellowish brown viscous substance was obtained and chromatographed on 5 g. of Florisil. White crystals (34 mg.) obtained from the benzene and benzene-$CHCl_3$ (10:90∼50:50) eluates, were assigned as the mixture of the dehydration products from the IR spectrum. Light yellowish crystals (14 mg.), obtained from the $CHCl_3$ and $CHCl_3$-MeOH (98:2∼90:10) eluates, were acetylated with 1 ml. of pyridine and 0.5 ml. of Ac_2O for 5 hr. on a water bath, then the reaction mixture was poured into H_2O and extracted with Et_2O. The Et_2O extract was chromatographed on 2 g. of alumina (Brockmann). The yellowish brown crystals (6 mg.) obtained from the benzene-$CHCl_3$ (50:50) eluates, were recrystallized from MeOH to 2 mg. of white needles, m.p. 198∼203°. This was identical in melting point and IR spectra with (VIb) and showed no depression of mixed melting point.

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Summary

A new steroidal sapogenin isolated from *Heloniopsis orientalis* (THUNB.) C. TANAKA was named "heloniogenin." The chromic acid oxidation of this sapogenin yielded gentrogenin. Gentrogenin acetate was also obtained with the chromic acid oxidation of heloniogenin 3-acetate. Of two isomers derived from gentrogenin with the metal hydride reduction, $3\beta,12\alpha$-diol was identified with heloniogenin. The structure of heloniogenin was confirmed as 25D-spirost-5-ene-$3\beta,12\alpha$-diol.

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198. Masao Nishikawa, Hiroyuki Mima, and Tokunosuke Kanzawa :

Infrared Spectra of Thiourea and its Inclusion Compounds. I. Vibrational Spectrum of Rhombohedral Thiourea.[*1]

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Thiourea, similar to urea, forms a kind of clathrates with various organic compounds. This property, discovered originally by Angla,[1,2] has been the subjects among many investigations. Detailed X-ray diffraction studies, carried out by Schlenk[3] and Lennè[4] revealed that, in the presence of suitable guest molecules, the crystal structure of thiourea was altered from a rhombic to a rhombohedral form. The guest molecules were enclosed in a hexagonal channel of about 5.8 Å in diameter, nearly 1 Å longer

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[*2] Juso-Nishino-cho, Higashiyodogawa-ku, Osaka (西川正夫, 美間博之, 神沢得之助).

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than that of urea. Therefore, branched-chain or cyclic compounds can be retained in the thiourea channel, whereas urea complexes are formed mostly with straight chain molecules. Such behaviors of urea and thiourea have drawn a great deal of attention, and interesting applications have been found in various fields. In our laboratories, Mima[5~8] has successfully utilized thiourea adducts for stabilization of medicines and for extraction or isolation of active components from essential oils.

Infrared investigations on inclusion compounds, mainly urea adducts, have also been reported. Stuart[9] showed the relationship between frequencies of NH stretching vibrations and hydrogen bond strength in urea crystals. Though Rodell and Hunt,[10] Barlow and Corish,[11] Fischer and Mcdowell,[12] and Mecke and his colaborators[13,14] discussed further on urea complex, any detailed studies on thiourea adducts have never been learned.

In the course of the research on pharmaceutical applications of thiourea adducts, specific changes of infrared spectrum have been also realized and reported briefly in the previous papers.[5~8] It seems to be necessary, to prepare more details especially in respect to dichroismic study of an adduct crystal.

Experimental

Eighteen kinds of inclusion compounds were examined. They were prepared by addition of guest molecules to a saturated methanolic solution of thiourea, except such unstable complexes as pyridine-, isoctane- and CCl_4-adducts, preparations of which were accomplished by mixing finely powdered thiourea with the corresponding compounds. Dioxane may be used as a solvent in place of MeOH but a care should be given since dioxane itself may form an adduct with thiourea under certain conditions. Deuterated thiourea was prepared by two recrystallizations of thiourea (500 mg.) from 5 cc. of D_2O (99.7%) in an air tight vial. On dissolving decaline into a hot anhydrous dioxane solution of thiourea-d_4, followed by standing at room temperature for several hours, deuterated inclusion crystals were separated to needles.

Spectroscopic measurements were conducted with a Perkin-Elmer IR spectrophotometer, Model 21 and 221 through NaCl prism and prism-grating interchange respectively. KBr and LiF prisms were also used to complement informations. The complexes were measured as Nujol and perfluorocarbon mulls. Hexachlorobutadiene was found to be unsuitable to a dispersing agent sinceit sometimes decomposed adducts by dissolving out the guest molecules. KBr disk technique was not recommended when the included compound was volatile. Some of the complexes were very unstable and may be decomposed while drying. In such a case the complex crystals filtered were covered with Nujol immediately after drying on a clay plate to prevent volatilization of the fillings. Another method to handle such unstable complexes was to measure spectra in the presence of excess guest molecules as suggested by Mecke.[13]

Orientation of adduct crystals were accomplished by gradual evaporation of their methanolic solution on a NaCl or a KBr plate. Rhombohedral crystals grew in direction of C-axis (optic axis), which was confirmed by observation of extinction angle on the universal stage under a microscope for the petrology. Nujol was applied thin over the crystal surface so as to reduce light scattering and to protect the complex from decomposition during measurement. AgCl and KRS-5 windows could not be used as they reacted with thiourea. Wave numbers were calculated using H_2O vapour, NH_3, CO_2, liquid indene, and polystyrene films as standards.

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Discussion

Infrared studies of thiourea have been conducted by Stewart,[15] Waldron,[16] Yamaguchi and her colaborators,[17] and Kutzelnigg and Mecke.[18] Raman data are available to Edsall's,[19] Kohlrausch's[20] Schrader's[21] papers. The spectra obtained in the present work are shown in Figs. 1~3.

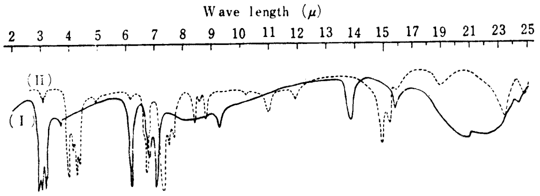

Fig. 1. Infrared Absorption Spectra
(I) Thiourea of rhombic crystal
(II) Thiourea-d$_4$ of rhombic crystal

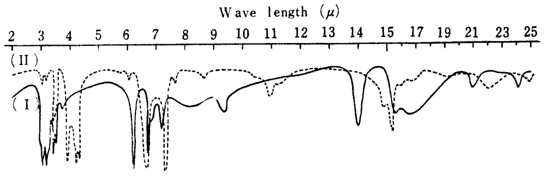

Fig. 2. Infrared Absorption Spectra
(I) Thiourea of rhombohedral crystal
(II) Thiourea-d$_4$ rhombohedral crystal

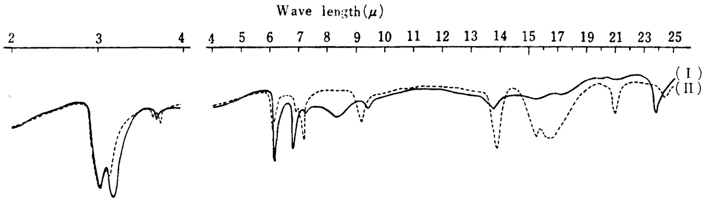

Fig. 3. Infrared Spectra of Rhombohedral Thiourea in Polarized Light

The bands obviously due to guest molecules are substracted from spectra.

(I) Absorptions observed with the light polarized parallel to the *C*-axis of crystal.
(II) Perpendicular to it.

There is a slight difference among the spectra of inclusion compounds, but they are essentially the same.*[3]

Ordinary thiourea crystallizes in a lattice of rhombic structure with the space group D_{2h}^{16} —$P_{2_1/n\ 2_1/m\ 2_1/a}$(Fig. 4 (a)). The molecules are situated at the special position of C_s symmetry, the mirror being perpendicular to the N-C-N plane. Very recently, approximate planarity of thiourea molecules was proved by electron diffraction[22] and nuclear magnetic resonance[23] studies. Accordingly, neglecting the effect of a crystal field, it can be treated as a C_{2v} structure. The assignment of infrared bands on this basis has been carried out by several workers and the results are listed in Table I, together with that of the present study.

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*[3] Further study at this point will be reported later elsewhere.

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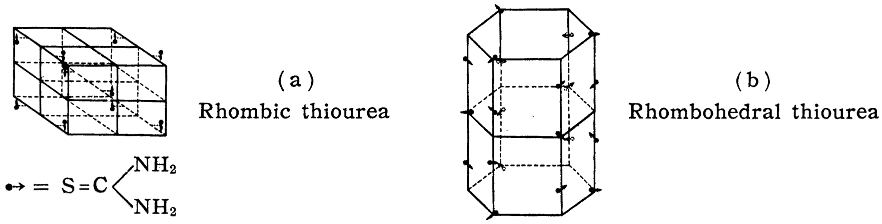

(a) Rhombic thiourea

(b) Rhombohedral thiourea

Fig. 4. Crystalline Structure of Thiourea

Table I.

	Assignment	Yamaguchi, *et al.*[17] Frequency cm^{-1} Calcd.	Obsd	Stewart[15] Frequency cm^{-1}	Present work Rhombic thiourea	Rhombohedral thiourea Frequency	Dichroism
A_1	ν_{NH}			3258	3375	3290	
	ν_{NH}			3097			
	δ_{NH}	1619	1610	1617	1611	1632	⊥
	$\nu_{C=S}$	1450	1417	1413	1414	1389	⊥
	ρ_{NH}	1059	1083	1086	1086	1088	⊥
	ν_{C-N}	757	730	730	731	715	⊥
	δ_{C-N}	498	488	463	488	477	⊥
A_2	ω_{NH}			577			in active
	τ_{NH}			505			in active
B_1	ν_{NH}			3365	3275	3290	
	ν_{NH}			3156			
	δ_{NH}	1623	1625	1617	1611	1617	//
	ν_{C-N}	1473	1470	1473	1472	1486	//
	ρ_{NH}	1153	1114	1086	1180	1210	//
	δ_{NCS}	462	415	486	412	415	//
B_2	ω_{NH}			769	460	613	⊥
	τ_{NH}			411		408	⊥
	π_{NCS}			629	635	649	⊥

ν=stretching, δ=bending, ρ=rocking, ω=wagging, τ=twisting, π=out-of-plane bending.

The crystal system of thiourea adducts is rhombohedral (space group D^6_{3d}—$R^{\overline{32}}/c$) and the host molecules occupy the C_2 site position. (Fig. 4 (b)). Since the rotational axis of C_2 is perpendicular to the C-axis of the crystal, the C=S bond has to be orientated normal to the needle axis. Furthermore, as the plane constructed by the four heavy atoms (N_2CS) is nearly parallel to the C-axis, it would safely be anticipated that the A_1 and B_2 (out-of-plane) modes of the vibrations should have the polarization vectors perpendicular to the C-axis and the polarization of the B_1 modes should coincide with the direction of the crystal axis. Hence, a study of orientated crystals with polarized light should supply useful information about the vibrational assignment of rhombohedral thiourea. Cyclohexanone- and decaline-thiourea adducts have been chosen for this purpose because of their stability and facility to preparation. The results obtained are shown in Fig. 3 and tabulated in Table I.

Almost all bands exhibit remarkable dichroism as expected. The only exception is the band at 3290 cm^{-1} which is attributable to NH stretching vibrations. The same behavior has been observed on the band at 3375 cm^{-1} in rhombic thiourea by Badger and Waldron,[16] who have thoroughly investigated it with polarized light at low temperature (−185°C) and have concluded that it predominantly contained four NH fundamentals. The other two intensive bands of rhombic thiourea in this region have been accounted for overtones and combinations.

It is impossible at present to give accurate assignment on the bands of thiourea adducts in the 3 μ region, but the close similarity between the spectra of rhombic and rhombohedral thiourea crystals woul make it reasonable to assume that four NH stretching vibrations of rhombohedral thiourea might be converged to 3290 cm^{-1} and that the band at 3155 cm^{-1} might come from overtones and combinations whose intensities have increased owing to Fermi resonance. When the spectra of rhombic was compared with rhombohedral thiourea-d$_4$, the above presumption will be supported. The two strong and two weaker bands of rhombic thiourea-d$_4$ that occur between 2500 and 2000 cm^{-1} shift to lower frequencies in its adducts but the whole features are essentially the same in both spectra. Therefore, any remarkable changes in the NH stretching bands of thiourea could not be expected between rhombic and rhombohedral forms except the frequency shift to longer wavelength in the latter structure.

Although there were some technical difficulties in obtaining the orientated thin crystals of thiourea-d$_4$ adducts, the polarization of the bands could be determined qualitatively. The observed date are shown in Table II. The tentative assignment of ND stretching vibrations is tried from this experiment. The sequence of the bands coincides with that of rhombic thiourea.

TABLE II.

		Yamaguchi, *et al.*[17]		Present work		
Assignment		Frequency cm^{-1}		Rhombic thiourea-d$_4$	Rhombohedral thiourea-d$_4$	
		Calcd.	Obsd.		Frequency	Dichroism
A$_1$	ν_{ND}			2549 s	2510 s	⊥
	ν_{ND}			2370 s	2360 s	⊥
	$\nu_{C=S}$	1317	1380	1380 s	1386 s	⊥
	δ_{ND}	1204	1190	1194 m	1185 w	?
	ρ_{ND}	882	910	914 m	920 m	⊥
	ν_{C-N}	704	668	669 s	658 s	⊥
	δ_{NCN}	440		428 s	400 m	
B$_1$	ν_{ND}			2442 m	2420 m	//
	ν_{ND}			2320 m	2318 s	//
	ν_{C-N}	1451	1500	1501 s	1519 s	//
	δ_{ND}	1188	1143	1144 m	1154 m	//
	ρ_{ND}	894	826	834 m	900 m	//
	δ_{NCS}	426				
B$_2$	π_{NCS}			650 s	677 m	⊥
	ω_{ND}				453 m	
	τ_{ND}					

s = strong, m = medium, w = weak.

The two scissors modes of NH bending vibrations are completely split. The in-phase mode (1632 cm^{-1}) appears at higher frequency than the out-of-phase (1617 cm^{-1}) in contrast with Yamaguchi's calculation for a rhombic thiourea model. On deuteration, these bands displaces to 1185 and 1154 cm^{-1} and their intensities decrease considerably, while both the C=S and C–N asymmetric stretching bands become intense and their frequency difference increases by about 50 cm^{-1}. These phenomena are observed in both crystal systems.

In the spectra of thiourea-d$_4$ adducts, there are two absorption bands attributable to NH out-of-phase rocking vibrations. The one is a broad band centered at 1210 cm^{-1} and the other has weaker peak at 1056 cm^{-1}. Both have perpendicular dichroism and therefore belong to the B$_1$ modes. The introduction of ND groups in thiourea adducts causes disappearance of these bands and a new broad band of perpendicular dichroism appears near 900 cm^{-1}, which is overlapped with the parallel polarization band at 920 cm^{-1}. The frequency ratio of 1210 and 900 cm^{-1} is 1.34 which agrees well with the theoretical value calculated as NH rocking mode. Consequently, the identification of the band at 1210 cm^{-1} to this mode seems to be valid.

In potassium bromide region notable changes take place in the spectrum of thiourea when an adduct was formed. The very broad band having two peaks at 488 and 460 cm^{-1} disappears leaving a band of medium intensity at 477 cm^{-1} and a new broad band is observed at 613 cm^{-1}. As the NH wagging vibration seems to be much more sensitive to minor changes in molecular association than the C–N bending mode, it is reasonable to assign the band at 613 cm^{-1} to the former mode. Again, the assignment has been acertained by deuterium exchange technique. On replacing NH with ND, the band shifted to 453 cm^{-1} the frequency ratio being 1.35.

In order to confirm the whole assignments discussed above, the product rule has been applied to A_1 and B_1 modes excluding NH stretching vibrations. The calculated values based on our assignments are in good agreement with the predicted values, the discrepancy being within 3% (Table III).

TABLE III.

	A_1 mode		B_1 mode	
	Calcd.	Obsd.	Calcd.	Obsd.
Rhombic thiourea	2.08	2.05	1.94	1.99
Rhombohedral thiourea		2.11		—

The most remarkable differences between the spectra of rhombic and rhombohedral thioureas are the raising of NH wagging frequency and the shift of NH stretching bands to lower frequencies. These displacements would be explained by an increase in the strength of intermolecular hydrogen bonds in an adduct crystal, similarly to the case of urea adduct. The strengthening of the hydrogen bonds might, in turn, lead rhombohedral crystal to be more favorable to rhombic one, provided that some of foreign molecules would fill the hexagonal space formed in the former crystal. Indeed, this might be one of the causes for the formation of clathrate compounds by urea and thiourea.

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Summary

Infrared spectra of thiourea and its adducts were determined in the region between 4000 and 400 cm^{-1} with a high resolution spectrophotometer. The spectra of adducts were almost similar. Through an investigation with polarized light on orientated thin crystals of adducts, nearly all fundamental bands were assigned. The assignments were also performed to the absorption bands of deuterated thiourea and its inclusion compound with decaline.

The results were examined with the product rule, the agreement being fairly good. Considerable changes were observed in NH stretching vibrations and wagging one, which showed strengthening of the intermolecular hydrogen bonds. The energy gain owing to this change would stabilize the adduct crystal.

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