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Fluorometric Study on the Metal Chelates of Flavone Derivatives. II.¹⁾ Correlation between Fluorescence Emission and the Carbonyl Stretching Frequency

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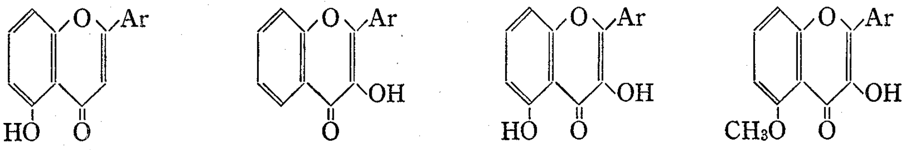
In the present paper, it has been described on a relationship between the fluorescence emission and the carbonyl stretching frequency of flavone derivatives. Non-fluorescent ligands (type I, III in Chart 1) show their carbonyl frequencies in the 1645—1650 cm^{-1} region, while fluorescent ligands (type II, IV) give those in the 1610—1620 cm^{-1} region and cause a remarkable increase of the fluorescence intensity by forming of chelates with some metals such as beryllium, aluminum, magnesium, thorium, yttrium. Further evidence is found by examining the chemical shift of 2-proton in several chromone derivatives. That of 3-hydroxychromone is noteworthily lower than those of the other chromone derivatives, indicating the more aromaticity of its pyrone ring. From these data, it is concluded that introduction of a hydroxyl group into 3-position of flavone causes the remarkable lowering of carbonyl frequency and the increase of aromaticity of pyrone ring, which is very likely responsible for the fluorescence emission.

In the previous paper,(1) we reported on the correlation between fluorescence intensity and structure of beryllium chelates of flavone derivatives, in which it was observed that the structures of type I, III in Chart 1 do not form fluorescent chelates, while the structures of type II, IV fluoresce by themselves and form fluorescent metal chelates with some kinds of metal ions such as beryllium, aluminum, magnesium, thorium, and yttrium. From these results, it was discussed that the fluorescence emission depends largely on the chelation formed between 4-carbonyl group and 3-hydroxyl group. In the present work, it has been described on a relationship between the fluorescence emission and the carbonyl stretching frequency.



I II III IV

Chart 1. Four Types of Flavone Derivatives

Result and Discussion

Table I lists the wave numbers for carbonyl absorption band of derivatives and fluorescence intensity of flavone derivatives, their magnesium and aluminum chelates. From these experimental results, an interesting correlation is found between the fluorescence emission and the carbonyl frequency of flavone derivatives.

None fluorescent ligands (type I, III in Chart 1) give bands due to the carbonyl group in the 1645—1650 cm^{-1} region, while fluorescent ligands (type II, IV) give those in the 1610—1620 cm^{-1} region. Of several investigations on the infrared spectra of the flavonoid already, reported

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1) Part I: T. Hayashi, K. Hara, S. Kawai, and T. Ohno, *Chem. Pharm. Bull.* (Tokyo), **18**, 1112 (1970).
2) Location: *Mitahora, Gifu.*

Table I. $\nu_{C=O}$(cm^{-1}) and Fluorescence Intensity of Flavone Derivatives

Compound	$\nu_{C=O}$(cm^{-1})		Fluorescence intensity		
	CCl$_4$-soln.	KBr-disk	Ligand	Mg(II)-chelate	Al(III)-chelate
Flavone	1650	1640	−		
5-OH-Flavone	1650	1650	−	−	−
5-OMe-Flavone	1650	1650	−		
3-OH-2′-OMe-Flavone	1620	1615	+	++	++++
2′,3-OMe-Flavone	1645	1640	−		
3,5-OHFlavone	1645	1640	−	−	−
3-OH-5-OMe-Flavone	1620	1620	+	+	++++
5-OH-3-OMe-Flavone		1640	−	−	−
3,5-OMe-Flavone		1640	−		
Quercetin		1655	−	+	+++

the most extensive, perhaps, have been the studies of Hergert and Kurth,[3] Shaw and Simpson,[4] and Looker and Hanneman.[5] However, no adequate interpretation has been offered to the shifts toward lower carbonyl frequencies of 3-hydroxyl derivatives, compared with those of the 5-hydroxyl derivatives. Looker and Hanneman reported that structures, Ia, Ib, Ic, Id, Ie shown in Chart 2, make sufficiently important resonance contributions to the structure of the flavone molecule, in which no hydrogen bonding is possible.

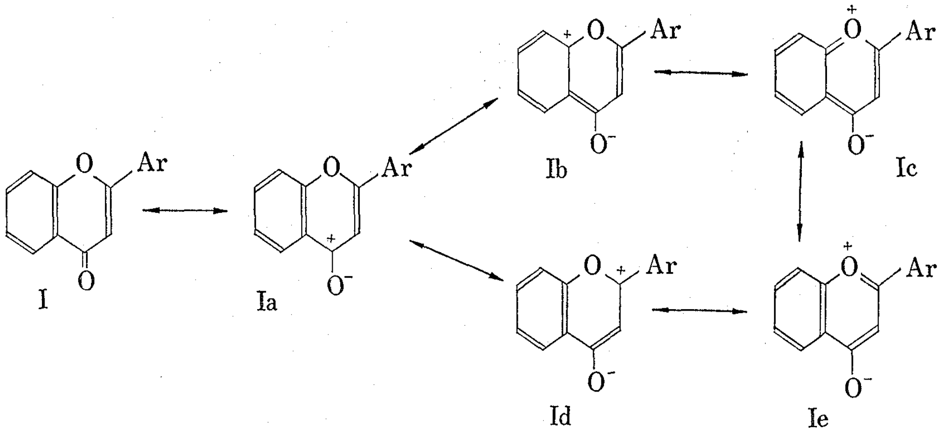

Chart 2

Introduction of a hydroxyl group into 3-position of flavone (type II) causes a remarkable frequency shift of the carbonyl absorption band to longer wave length, and methylation of the 3-hydroxyl group shifts the band back to the 1645—1650 cm^{-1} region. These phenomena are interpreted from a well-known observation in infrared spectroscopy that hydrogen bonding causes the shifts toward lower carbonyl frequencies, indicating more participations of ionic resonance forms IIa, IIb, IIc shown in Chart 3, from which the promotion of the aromaticity of pyrone ring would be expected to cause a fluorescence emission.

In the case of the type I which does not fluoresce, 5-hydroxyl group forms a strongly conjugated hydrogen bonding with 4-carbonyl group. This increased stability of structure IIIa due to hydrogen bonding may compete with the contribution of the structures IIIb, IIIc, because the both resonance structures are formed by mutually opposing mechanisms. Therefore, the type I compounds may happen to give their carbonyl frequencies in the same region

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[3] H.L. Hergert and E.F. Kurth, *J. Am. Chem. Soc.*, **75**, 1622 (1953).
[4] B.L. Shaw and T.H. Simpson, *J. Chem. Soc.*, **1955**, 655.
[5] J.H. Looker and W.W. Hanneman, *J. Org. Chem.*, **27**, 381 (1962).

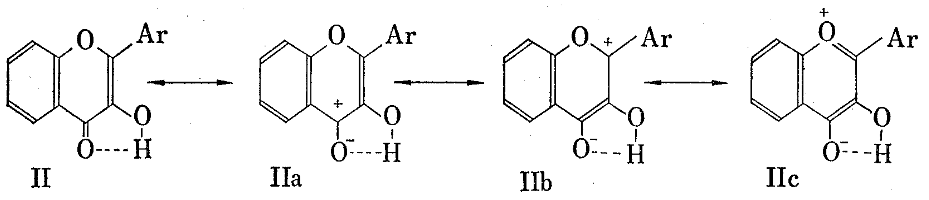

Chart 3

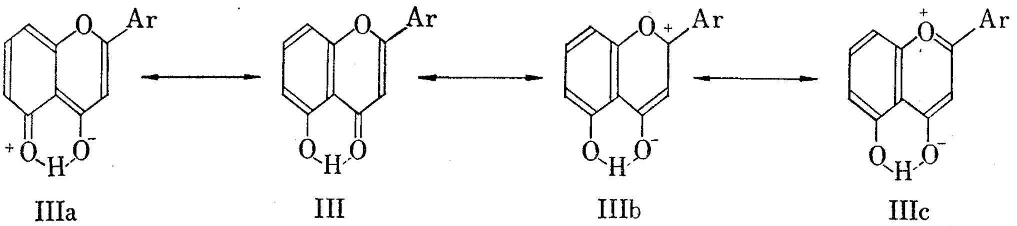

Chart 4

as flavone. Methylation of 5-hydroxyl group makes the strongly conjugated hydrogen bonding lose and the structure, IIIb, IIIc play important resonance contributions in 5-methoxyflavone. Consequently, it also give the carbonyl frequencies in the same region of 1645—1650 cm^{-1} as flavone.

In the case of the type III compounds having two hydroxyl groups in 3- and 5-position, as was stated in the previous paper, intramolecular hydrogen bonding is formed with 5-hydroxyl group, and their resonance seems to be similar to that of the type I compounds, in which as expected, their carbonyl frequencies occur in the 1645—1650 cm^{-1} region. Methylation of 5-hydroxyl group in the type III compounds (type IV) causes a hydrogen bonding with 3-hydroxyl group to form instead of 5-hydorxyl group. Consequently, the resonance forms seem to be similar to those of the type II compounds, which is likely responsible for the carbonyl shift to the 1610—1620 cm^{-1} region. Furthermore methylation of 3-hydroxyl group loses any intramolecular hydrogen bonding, and the resonance may be similar to that of the flavone molecule from a shift back of the carbonyl frequencies to the 1645—1650 cm^{-1} region. From these facts, the increase of aromaticity of pyron ring due to introduction of 3-hydroxyl group, is considered to play a predominant part on the fluorescence emission of flavone derivatives. As shown in the Table I, further evidence is found by a remarkably increase of the fluorescence intensity produced by formation of metal chelates with 3-hydroxyl group. This phenomenon seems to support the speculation described above, because in the metal chelates with 3-hydroxyl group, the ionic structures IIa, IIb, IIc are more stabilized by large electron-negativity of metal ion, and the aromaticity of pyron ring was considered to more increase than the case of 3-hydroxyflavone. In Table II are given the carbonyl frequencies and chemical shifts of 2-proton in chromone derivatives.

As would be expected, the carbonyl frequency of 3-hydroxychromone appears in the lower region than that of 3-methylchromone, and 3-methoxychromone causes a shift back to the

Table II. $\nu_{C=O}(\text{cm}^{-1})$ and Chemical Shift (τ) of Chromone Derivatives

Compound	$\nu_{C=O}(\text{cm}^{-1})$ CCl_4-soln.	τ value of 2-H
3-Me-Chromone	1650	2.22
5-OH-Chromone	1655	2.15
5-AcO-Chromone	1665	2.30
3-OH-Chromone	1635	1.80
3-OMe-Chromone	1660	2.34

higher region. The carbonyl frequencies of 5-hydroxychromone and the acetyl derivative are slightly higher than that of 3-methylchromone. These phenomena are similar as those of flavone derivatives. It seems likely, therefore, that the resonance structures also are similar to those of flavone derivatives. The chemical shift of 2-proton in 3-hydroxychromone is noteworthily lower than those of the other chromone derivatives, indicating the increase of aromaticity of its pyrone ring. From data discussed above, it is concluded that introduction of a hydroxyl group into 3-position of flavone causes the remarkable lowering of the carbonyl frequency and increase the aromaticity of pyrone ring, which is responsible for the fluorescence emission. We are carrying out further studies on the aromaticity of pyrone ring by X-ray analysis.

Experimental

The instruments used in this work are Simadzu GSF-16 spectrofluorometer, JASCO DS-403G grating infrared spectrophotometer and JEOL NMR spectrometer Model JNM C-60HL (60M Hz). The fluorescence intensities were determined in the same condition as described in the previous paper.[1] The infrared absorption spectra of flavone and chromone derivatives were measured in carbon tetrachloride or in potassium bromide disk. The NMR spectra of chromone derivatives were measured in $CDCl_3$ using tetramethylsilane as an internal standard. Most of flavone derivatives were available as described in the previous paper.[1] Some flavone and chromone derivatives were prepared by the following method.

3-Methoxyflavone——3-Hydroxyflavone (0.2 g) was converted to 3-methoxyflavone by gently boiling for 1 hr with anhydrous potassium carbonate (0.4 g) and dimethylsulfate (0.32 g) in acetone solution. The product was recrystallized from ethanol. mp 112—113°, $FeCl_3$–reaction negative.

5-Methoxyflavone——2'-Hydroxy-6'-methoxychalcone (3.5 g) was converted to 5-methoxyflavone by boiling under reflux for 10 hr with SeO_2 (3.5 g) in amylalcohol (50 ml). The product was recrystallized from ethanol.

3-Methoxychromone——3-Hydroxychromone (0.05 g) in methanol was methylated with excess of diazomethane and the product was recrystallized from ethanol. mp 108—109°, $FeCl_3$–reaction negative.

5-Acetoxychromone——5-Hydroxychromone (0.5 g) was acetylated by gentle boiling for 1 hr with acetic anhydride (1 ml) and pyridine (a few drops) and product was recrystallized from ethanol. mp 117—118°.

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