Studies on Organic Reagents for Inorganic Analysis. IV. Syntheses of New Phenylfluorone Derivatives and their Reactions with Metal Ions

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Although numerous investigations have been published on the colorimetric determination of germanium(1-3), tin(4), titanium(5), and zirconium(6) with phenylfluorone (abbreviation for 2,3,7-trihydroxy-9-phenylfluorone), the research for the phenylfluorone derivatives is far from satisfactory. As is well known, phenylfluorone has some excellent properites as a colorimetric reagent. For instance, phenylfluorone has high sensitivity toward germanium, titanium, and zirconium, and germanium phenylfluoronate shows a high stability. However, it has some weak points such as small solubility of its chelates, somewhat low stability of the chelate of zirconium and undesirably high absorbance of the reagent solution at the wavelength used in the determination of germanium. Therefore, it is desirable to find out a new derivative which keeps the advantages and has no such difficulty. For this purpose, only 2, 3, 7-trihydroxy-9-(4'dimethylaminophenyl) fluorone was synthesized by the author and his coworkers,(7) and it was applied successfully to the colorimetric determination of germanium by Kimura and Asada(8). Subsequently, some other derivatives, i. e., 2, 3, 7-trihydroxy-9-(3'-nitrophenyl) fluorone, 2, 3, 7-trihydroxy-9-(4'-nitrophenyl) fluorone and 2, 3, 7-trihydroxy-9-(2'-sulfophenyl) fluorone have been synthesized by a similar procedure. These compounds except 3'-nitrophenyl-fluorone(9) have never been described in the literature.

Experimental and Results

Syntheses of Derivatives.—*Reagents Used.*-*m*-Nitrobenzaldehyde, *p*-nitrobenzaldehyde, and benzaldehyde-*p*-sodium sulfonate were first grade reagents prepared by Tokyo Kasei Ind., Co., Japan, and used without further purification. Hydroxyhydroquinone triacetate was synthesized(10) from commercial *p*-benzoquinone, acetic anhydride and concentrated sulfuric acid, and recrystallized twice or thrice from 95% ethanol. Commercial 95% ethanol was used.

Procedures for Syntheses.—For the synthesis of 3'- or 4'-nitro derivative, 20 g. of *m*- or *p*-nitrobenzaldehyde was dissolved in 300 ml. of 20% ethanol in a 500 ml. Erlenmeyer's flask. To the solution were added 100 ml. of ethanolic solution, containing 70 g. of hydroxyhydroquinone triacetate and 10 ml. of concentrated sulfuric acid. A deep red color appeared in the solution by heating it on a steam bath for two or three hours. The solution was allowed to stand for about three weeks. The resulting red crystalline precipitate was filtered, washed with warm 20% ethanol, and suspended in 400 ml. of water at controlled pH of 4. The hydrolyzed precipitate, whose color was deep red, was filtered, washed and dried in a vacuum desiccator.

For 2'-sulfo derivative, the procedure was somewhat different from that described above because of a considerable solubility of the sulfo derivative. Twenty grams of *o*-sulfobenzaldehyde was dissolved in 300 ml. of 20% ethanol in a 500 ml. round-bottom flask. To the solution were added 100 ml. of ethanol containing 70 g. of hydroxyhydroquinone triacetate and 30 ml. of concentrated hydrochloric acid. The solution was heated on a steam bath for two or three hours. Red color appeared in the solution. Even after being allowed to stand for several weeks, no precipitate was formed. The solution was then concentrated on a steam bath by vacuum evaporation. A red precipitate with greenish fluorescence was formed when the volume of the solution was reduced to nearly a half. The crystalline precipitate was filtered, washed with warm 20% ethanol roughly, and suspended in 400 ml. of water at pH 4. The hydrolyzed precipitate, of orange-yellow color which was considered to be sodium-sulfophenylfluorone was filtered, washed and dried. The orange yellow crystalline precipitate was dissolved or suspended in 1 l. of 95% ethanol containing 10 ml. of distilled hydrochloric acid on a steam

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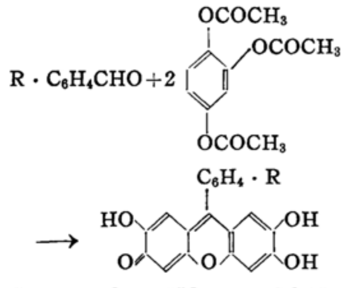
1) H. J. Cluley, *Analyst*, **76**, 523 (1951).
2) Y. Oka, T. Kanno and K. Shiba, *Japan Analyst (Bunseki Kagaku)*, **3**, 389 (1954).
3) C. L. Luke and M. E. Campbell, *Anal. Chem.*, **28**, 1273 (1956).
4) C. L. Luke, ibid., **28**, 1276 (1956).
5) H. Sano, *Japan Analyst (Bunseki Kagaku)*, **7**, 235 (1958).
6) K. Kimura and H. Sano, This Bulletin **30**, 80 (1957).
7) K. Kimura, H. Sano and M. Asada, ibid., **29**, 640 (1956).
8) K. Kimura and M. Asada, ibid., **29**, 812 (1956).
9) E. Heintschel, *Ber.*, **38**, 2878 (1905).
10) "Organic Syntheses, Collective Vol. I", John Wiley & Sons Inc., New York (1948), p. 317.

bath. The solution was allowed to stand for one or two days, and an orange red precipitate was obtained. The precipitate was filtered, washed, and dried in a vacuum desiccator.

The author is of the opinion that the following reactions occurred in this procedure.



R: m-NO_2, p-NO_2 or o-SO_3H.

in $\left\{\begin{array}{l} H_2O \\ C_2H_5OH \\ H_2SO_4 \text{ or } HCl \end{array}\right.$

The yields of 3′-nitro, 4′-nitro and 2′-sulfo derivative are 30, 21 and 25% of the theoretical, respectively.

Anal. of the 3′-nitro derivative. Found: C, 60.76; H, 3.70. Calcd. for $C_{19}H_{11}O_7N$: C, 62.47; H, 3.04%.

Anal. of the 4′-nitro derivative. Found: C, 60.25; H, 3.27. Calcd. for $C_{19}H_{11}O_7N$: C, 62.47; H, 3.04%.

Anal. of the 2′-sulfo derivative. Found: C, 56.03; H, 3.35. Calcd. for $C_{19}H_{12}O_8S$: C, 57.01; H, 3.02%.

Properties of the Products.—3′-Nitro derivative: m.p.>310°C, orange-red powder, insoluble in water, sparingly soluble in ethanol. Addition of mineral acid to an ethanolic solution of the compound increases its solubility giving a yellow color. This compound is easily soluble in alkaline solution, giving a faded red-violet color. 4′-Nitro derivative: m.p.>310°C, brownish red powder, insoluble in water, soluble in ethanol with difficulty. The general trend of the effect of acid or alkali on the solubility is similar to the case of 3′-nitro derivative. 2′-Sulfo derivative: m. p.>295°C, orange powder, (its addition compound with hydrochloric acid is composed of brownish needles having green fluorescence.) slightly soluble in water or in ethanol, giving yellow color and weak green fluorescence. The addition of a small amount of mineral acid to the solution increases its solubility slightly. The addition of sodium hydroxide greatly increses the solubility, giving red color and strong green fluorescence. In a strong alkaline solution, the color turns red-violet and the fluorescence disappears.

Absorption Spectra of the Solutions of the Derivatives.—The absorption spectra of the derivatives in an acidic and an alkaline solution are shown in Figs. 1a, b, c, d and e, together with those of phenylfluorone and dimethylamino-phenylfluorone for comparison. The absorption measurements were made with a Uvispek spectrophotometer and Beckman model DU spectrophotometer

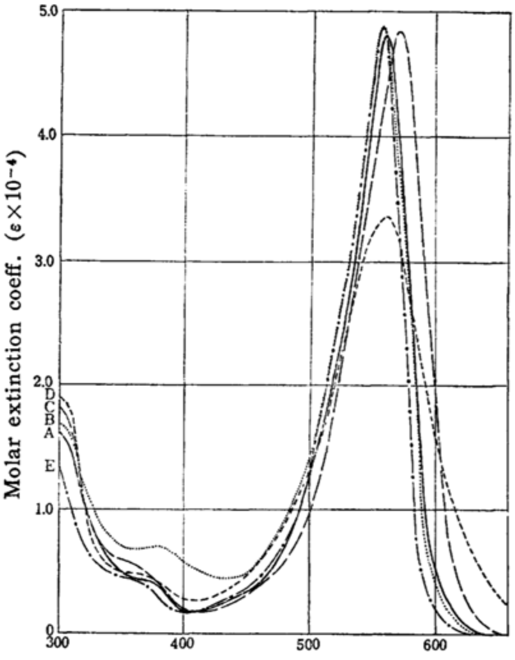


Fig. 1a. Absorption spectra of products in alkaline media.

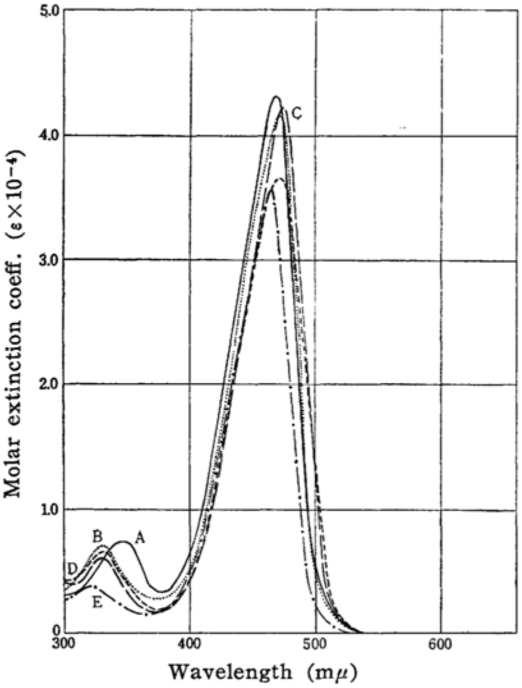


Fig. 1b. Absorption spectra of products in acidic media.

Curve A: Phenylfluorone ———
Curve B: 4′-Dimethylamino- 〃 ·········
Curve C: 3′-Nitro- 〃 — — —
Curve D: 4′-Nitro- 〃 ---------
Curve E: 2′-Sulfo- 〃 — · —

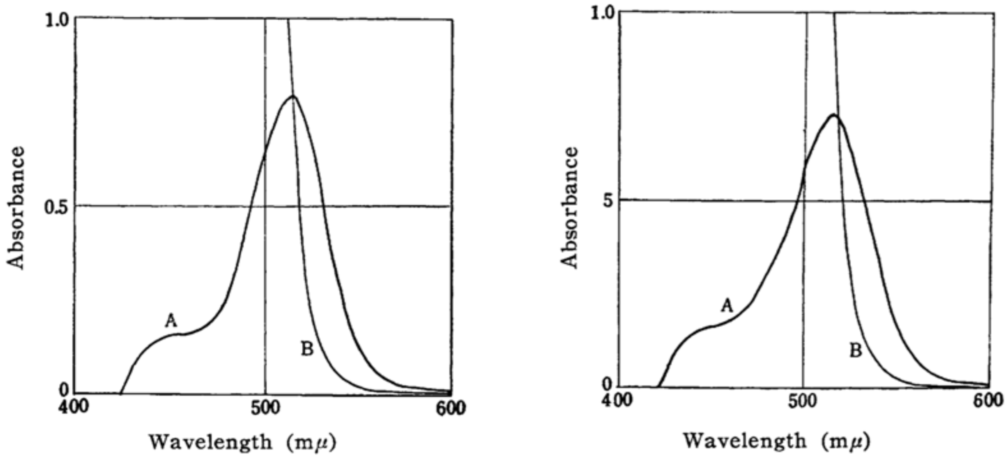


Fig. 2a.

Curve A. Germanium-4′-nitrophenylfluoronate
〃 B. Reagent only (1.0 N HCl solution)

Fig. 2b.

Curve A. Germanium-3′-nitrophenylfluoronate
〃 B. Reagent only (1.0 N HCl solution)

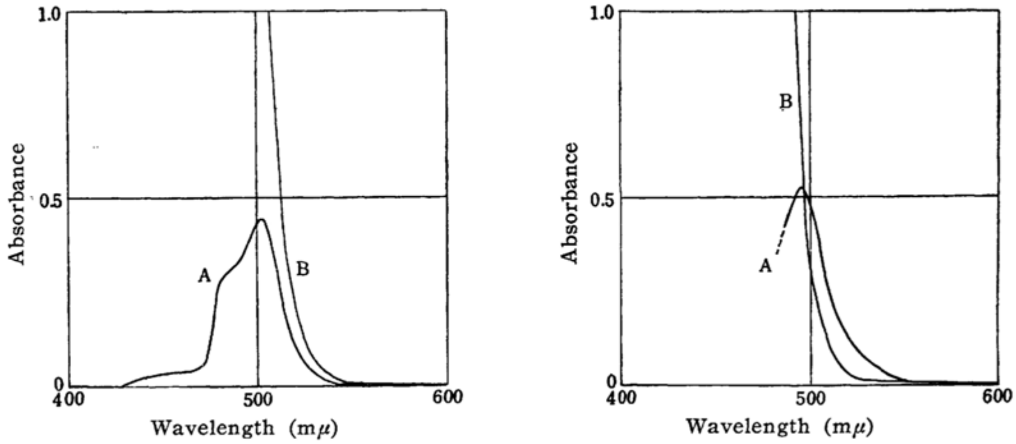


Fig. 2c.

Curve A. Germanium-4′-dimethylaminophenylfluoronate
〃 B. Reagent only (2.0 N HCl solution)

Fig. 2d.

Curve A. Germanium-2′-sulfophenylfluoronate
〃 B. Reagent only (0.1 N HCl solution)

Fig. 2a, b, c and d. Absorption spectra of germanium-fluoronates.

equipped with 1 cm. glass cells. All measurements were made with the blank solution as the reference.

Reaction of the Derivatives with Metal Ions.—*Reagents used.*—Germanium solution was prepared by dissolving water-soluble germanium dioxide (99.9% GeO_2) in hot water, and standardized gravimetrically. Zirconyl chloride solution and titanium chloride solution were prepared by dissolving zirconyl chloride octahydrate (containing 0.5% hafnium) and titanium tetrachloride in 1 N hydrochloric acid. Ethanolic solutions of phenylfluorone and its derivatives were prepared by dissolving 0.120 g. of the dyes* in 150 ml. of warm ethanol containing 1 ml. of 5.0 N hydrochloric acid, and diluting it to 200 ml. with ethanol. Gum arabic solution was prepared by dissolving 0.5 g. of gum arabic in 200 ml. of warm water. The solution was filtered when necessary. Analytical grade cyclohexanol was used without further purification.

Procedure.—Because the metal chelates of 3′- or 4′-nitro derivative are difficultly soluble in many solvents, all the absorbance measurements of the metal chelates were taken in the presence of a suitable stabilizer such as gum arabic or cyclohexanol. The light-scattering effect of the colloidal particle on the absorption spectra is negligible for several hours after the preparation of the solution. The effect of the stabilizer on the absorption maximum of the chelate was also negligibly small. Germanium (15.0 μg.), titanium (60.8 μg.), or zirconium (20.7 μg.) was taken in a 25 ml. volumetric flask. An

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* Because the solubility of the sulfo derivative is less than 0.06%, the supersaturated solution of the dye was prepared by dissolving corresponding sodium salt of sulfo derivative similarly. The precipitation of sulfo derivative appeared about two weeks after the preparation.

appropriate volume of hydrochloric acid was added to adjust the acidity of the final solution to desirable strength. Five ml. of ethanol, and 2.5 ml. of gum arabic solution (for germanium) or cyclohexanol (for zirconium) was added. To the solution was added 5 ml. of the phenylfluorone or its derivatives and the final volume of the solution was adjusted to 25 ml. with distilled water. The blank solution was prepared in the same way as that for the sample solution.

Reaction with germanium.—The germanium complexes of 4′- and 3′-nitrophenylfluorone are almost insoluble in ethanolic solution, whereas that of 2′-sulfophenylfluorone is soluble to the same extent as the 4′- and 3′-nitrophenylfluorone. The last two are almost insoluble in ethanolic solution, whereas germanium complex of 2′-sulfophenylfluorone is soluble to the same extent as that of 4′-dimethylaminophenylfluorone. The absorption spectra of the germanium chelates are shown in Figs. 2a, b, c and d. The absorbance of the solutions of germanium chelates at various acidities is illustrated in Fig. 3, including that of the phenylfluorone and 4′-dimethylaminophenylfluorone, together with that of the blank solutions at the same wavelengths for comparison.

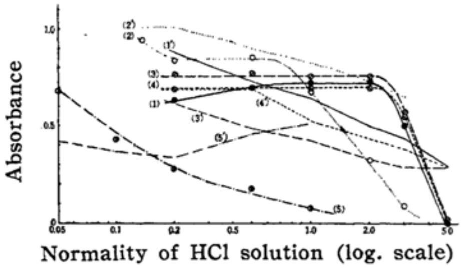

Fig. 3. Effect of acidity on germanium-fluoronates with germanium concentration fixed**.

Curve (1) Phenylfluorone (510 mμ)
〃 (2) 4′-Dimethylaminophenylfluorone (510 mμ)
〃 (3) 3′-Nitrophenylfluorone (520 mμ)
〃 (4) 4′-Nitrophenylfluorone (520 mμ)
〃 (5) 2′-Sulfophenylfluorone (500 mμ)
〃 (1′), (2′), (3′), (4′) and (5′) Blank solution, respectively.

Reaction with zirconium.—The zirconium complexes of 4′- and 3′-nitrophenylfluorone are slightly soluble in cyclohexanol-ethanol solution. Figs. 4a and b show the absorption spectra of the zirconium chelates. The reactivities of the dyes with zirconium at various acidities are illustrated in Fig. 5, together with the absorbance of the blank solutions at the same wavelengths. The colored chelates of 2′-sulfo- and 4′-dimethylaminophenylfluorone are found only in a lower acidity region, so they are excluded from the comparison.

Reaction with titanium.—The titanium complexes of 4′- and 3′-nitrophenylfluorone are fairly soluble in cyclohexanol-ethanol. The absorption spectra of the titanium chelates are shown in Figs. 6a and b. The reactivities of the dyes with titanium at various acidities are illustrated in Fig. 7, together with the absorbance of the blank solutions at the same wavelength. The stability of titanium chelates is lower than that of zirconium chelates at the same acidity. Colored chelates of 2′-sulfo- or 4′-dimethylaminophenylfluorone is not formed in the acidity above 0.05 N hydrochloric acid concentration.

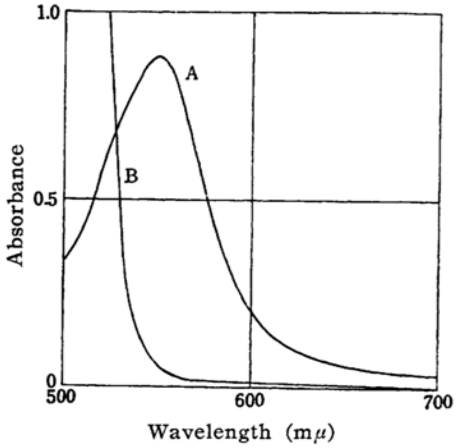

Fig. 4a.

Curve A. Zirconium-3′-nitrophenylfluoronate
〃 B. Reagent only (0.15 N HCl solution)

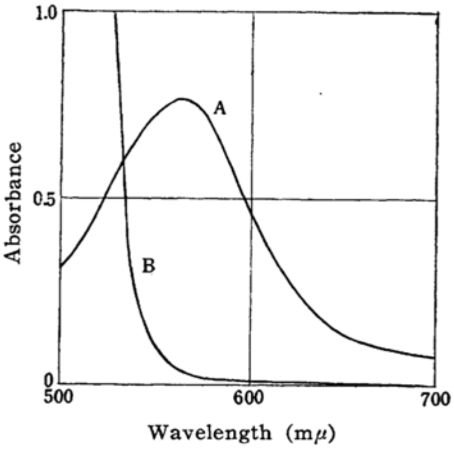

Fig. 4b.

Curve A. Zirconium-4′-nitrophenylfluoronate
〃 B. Reagent only (0.15 N HCl solution)

Fig. 4a and b. Absorption spectra of zirconium-fluoronates.

Discussion

The process in the syntheses of 3′-nitro, 4′-nitro, and 2′-sulfo derivatives is performed without such a difficulty as was

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** The absorbances were measured thirty minutes after the preparation of the solution. They slightly increase with increasing digestion time.

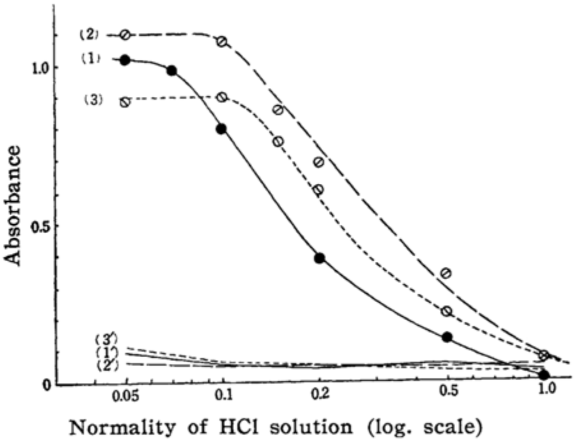

Fig. 5. Effect of acidity on zirconium-fluoronates with zirconium concentration fixed**.

Curve (1) Phenylfluorone (540 mμ)
〃 (2) 3′-Nitrophenylfluorone (550 mμ)
〃 (3) 4′-Nitrophenylfluorone (560 mμ)
〃 (1′), (2′) and (3′) Blank solution respectively.

experienced in the formation of oily polymeried products in the synthesis of phenylfluorone. The absorption spectra of the products resemble closely that of phenylfluorone and 4′-dimethlylaminophenylfluorone. The value of shifts of their absorption maxima with variation of the medium from acidic to alkaline agrees with one another and lies at the range from 90 to 95 mμ. In 3′-nitro and 4′-nitro derivative, the absorption maximum shifts toward a longer wavelength than that of phenylfluorone, as is expected because of the increasing electronegativity of the carbon atom at position 9 caused by the " inductive " or the " mesomeric " effect of the nitro group. On the other hand, the absorption maximum shifts toward the shorter side in 2′-sulfo derivative, suggesting that the effect of the phenyl group is reduced by the steric hindrance of the sulfo group at position 2′. These facts convince the author that the products correspond to the compounds named. The wavelength of absorption maximum in the metal chelate of phenylfluorone derivative can be estimated from the maximum wavelength of the phenylfluorone derivative anion and of the metal phenylfluoronate. As a first approximaton, the estimation was performed as follows:

$$\frac{\boldsymbol{hc}}{\lambda_{\max}} = \varDelta E = \varDelta E_0 + \varDelta\varepsilon + \varDelta'\varepsilon$$

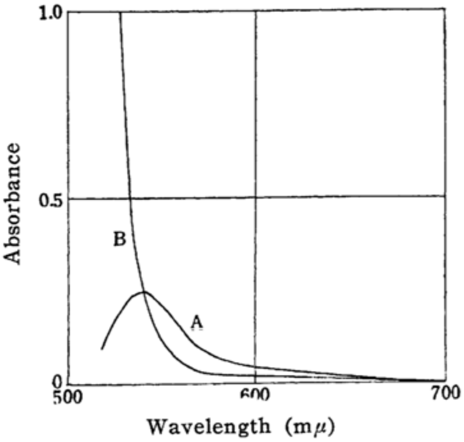

Fig. 6a.

Curve A. Titanium-4′-nitrophenylfluoronate
〃 B. Reagent only (0.1 N HCl solution)

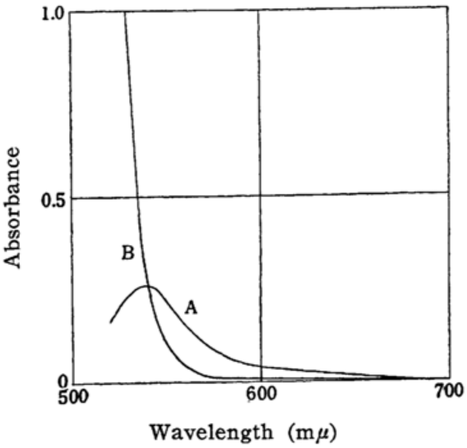

Fig. 6b.

Curve A. Titanium-3′-nitrophenylfluoronate
〃 B. Reagent only (0.1 N HCl solution)

Fig. 6a and b. Absorption spectra of titanium-fluoronates.

where $\varDelta E_0$ is, the energy difference between the highest ground state and the lowest excited state in phenylfluorone anion,* $\varDelta\varepsilon$ the effect of perturbation caused by chelate formation and is calculated from the absorption maximum of the metal phenylfluoronate,* and $\varDelta\varepsilon'$ the

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** See the foot note in Fig. 3.

* The value, $\varDelta E_0$, $\varDelta\varepsilon$, or $\varDelta\varepsilon'$, is expressed as follows, respectively:

$\varDelta E_0=\boldsymbol{h}^2(N+1)/8\boldsymbol{mc}L^2=\boldsymbol{hc}/\lambda_{\max.\ \text{phenylfluorone anion}}$,

$\varDelta\varepsilon=(1-1/N)V_0=\boldsymbol{hc}(1/\lambda_{\max.\ \text{metal phenylfluoronate}}-1/\lambda_{\max.\ \text{phenylfluorone anion}})$,

$\varDelta\varepsilon'=4V_1a/L=\boldsymbol{hc}(1/\lambda_{\max.\ \text{phenylfluorone anion}}-1/\lambda_{\max.\ \text{derivative anion}})$.

For the information on the physical meaning of V_0, V_1 a, etc., see references; H. Kuhn, *J. Chem. Phys.*, **17**, 1198 (1949), *Helv. Chim. Acta*, **34**, 2371 (1951); H. Sano, This Bulletin, **30**, 790 (1957).

TABLE I

ABSORPTION MAXIMUM OF METAL CHELATES (Å)

		(H)	Ti	Ge	Zr	Dye anion
Phenylfluoronate	(obsd.)	4680	5250	5080	5400	5600
3′-Nitro 〃	(obsd.)	4750	5390	5150	5500	5700
	(calcd.)	4750	5338	5162	5487	—
4′-Nitro 〃	(obsd.)	4720	5390	5150	5620	5620
	(calcd.)	4694	5268	5096	5419	—
2′-Sulfo 〃	(obsd.)	4660	—	4950	—	5570
	(calcd.)	4659	—	5056	—	—
4′-Dimethylamino 〃	(obsd.)	4720	—	5030	5200	5570
	(calcd.)	4659	—	5056	5372	—
4′-Hydroxy 〃	(obsd.)*	4590	—	5050	—	—

* This value was given by Dr. Takuji Kanno.

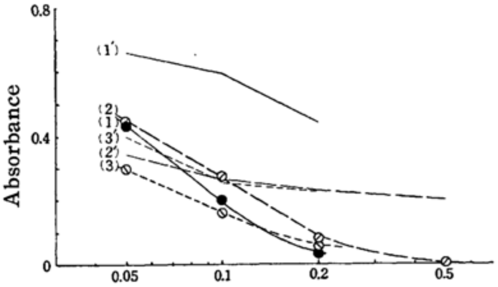

Fig. 7. Effect of acidity on titaniumfluoronates with titanium concentration fixed**.

Curve (1) Phenylfluorone (525 mμ)
〃 (2) 3′-Nitrophenylfluorone (540 mμ)
〃 (3) 4′-Nitrophenylfluorone (540 mμ)
〃 (1′), (2′) and (3′) Blank solution respectively.

effect of perturbation caused by the substituent introduced into the phenyl group and is calculated from the absorption maximum of derivative anion.* The wavelengths calculated and observed for the chelates are shown in Table I.

Only the 4′-nitro derivative shows a certain anomaly in the absorption maximum of the dye anion, which is expected to be a longer wavelength than the observed from its strong electron-attracting effect, and in the absorption maximum of the metal chelate, which lies at a longer side than that expected. The low value of molar extinction of 4′-nitro derivative and these anomalies may be due to the fact that a mesomeric group is substituted at the 4′-position, and that the interaction between $\Delta\varepsilon$ and $\Delta\varepsilon'$ was neglected in the calculation of the absorption maximum of the chelate.

From the reactivities of the derivatives with metal ions shown in Figs. 3, 5, and 7, it will be seen that the stability of the chelate increases with an increasing "inductive" or "mesomeric" effect of the substituent. The low stability of 2′-sulfophenylfluoronate may be due to the steric hindrance of the 2′-sulfo group. This shows that the stability of the chelate increases with the increasing ionizability of the donor oxygen atom of the dye. The absorbance of the 3′-nitrophenylfluoronate is higher than that of the others, except that of 4′-dimethylaminophenylfluoronate, whereas the absorbance of the blank solution is the lowest and the stability is greater than in the case of the others. This suggests the compound may be excellent as the colorimetric reagent for the determination of metal ions such as germanium or zirconium. It will be expected that the other derivatives, e. g., 3′-sulfo, 4′-sulfo, 3′, 4′-disulfo, 3′, 3″-dinitro, and 3′-amino derivative will be useful from the results above mentioned. They are under investigation.

Summary

2, 3, 7-Trihydroxy-9-(3′-nitrophenyl) fluorone, 2, 3, 7-trihydroxy-9-(4′-nitrophenyl) fluorone, and 2, 3, 7-trihydroxy-(2′-sulfophenyl)fluorone were synthesized by a comparatively simple procedure, for the purpose of studying the reaction between the colorimetric reagent and metal ions and to search for a useful colorimetric reagent. The effects of the substituents introduced on the absorption maxima of the dyes and the metal chelates formed, and on the reactivities of the dyes with metal ions such as germanium(IV), zirconium(IV), and titanium(IV). 2′-Sulfophenylfluorone metal chelates are soluble in an ethanolic or cyclohexanol-ethanolic solution. 3′-Nitrophenylfluorone is most excellent as the colorimetric reagent for the determination of metal

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** See the foot note in Fig. 3.

ions because of the high stability, high sensitivity and low absorbance of the blank solution.

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