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Note

Kinetic studies of epimerization of cobalt(III) complexes by means of high-performance liquid chromatography on a cation exchanger derived from TSKgel G3000PW

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When kinetically unstable species are subjected to column chromatographic separation, they are transformed gradually into other species in the column, and thus the patterns of chromatograms depend on the relative rates of separation and transformation[1]. In order to study kinetics of reactions in solution by high-performance liquid chromatography (HPLC), the separation should be performed much faster than the transformation occurs, so that transformation during chromatography can be negligible. In a previous paper[2], we reported that a cation-exchanger, sulphoethyl (SE)-Toyopearl is suitable for use in HPLC under a reasonable pressure, and this method was successfully applied to kinetic studies of the inversion at the selenium atom of $[Co(acac)_2(CH_3SeCH_2CH_2NH_2)]^+$ (acac = 2,4-pentanedionate ion).

An HPLC column packed with a strong cation-exchanger with sulphopropyl groups derived from TSKgel G3000PW was found to be more effective than an SE-Toyopearl column for separation of the isomers of metal complexes. In this paper, we describe the application of HPLC on this exchanger to kinetic studies of inversion at the selenium atom of $[Co(Clacac\ or\ Meacac)_2(CH_3SeCH_2CH_2NH_2)]^+$ (Clacac = 3-chloro-2,4-pentanedionate ion, Meacac = 3-methyl-2,4-pentanedionate ion) and that at the secondary amine nitrogen atom of $[Co(acac)_2(C_6H_5NHCH_2CH_2NH_2)]^+$.

EXPERIMENTAL

The cation-exchanger (exchange capacity, $0.14 \cdot 10^{-3}$ equiv. cm^{-3}) used in this study was a gift from Toyo Soda (Tokyo, Japan). According to the manufacturer, this exchanger was developed by introducing sulphopropyl groups into TSKgel G3000PW[3], which is a hydrophilic-polymer-based gel carrying aliphatic hydroxyl groups. The allyl groups introduced into the hydroxyl groups of the gel were transformed into sulphopropyl groups by the oxygen-induced, anti-Markownikoff addition of sodium hydrogen sulphite to the C=C double bonds[4]. A similar cation-exchanger derived from TSKgel G5000PW is commercially available under the tradename of TSKgel SP-5PW.

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Kinetics

A racemic pair of diastereomers, $\Delta(S)\Lambda(R)$-[Co(Clacac or Meacac)$_2$-($CH_3SeCH_2CH_2NH_2$)]ClO_4[5] (*ca.* 10^{-4} mol dm^{-3}) in 0.05 mol dm^{-3} sodium sulphate was epimerized at 40°C. Portions of the reaction mixture were withdrawn at intervals and then chromatographed (sample volume, $4 \cdot 10^{-3}$–$6 \cdot 10^{-3}$ cm^3) with a column (7.5 × 0.75 cm I.D.) of the cation-exchanger and 0.05 mol dm^{-3} (Clacac complex) or 0.025 mol dm^{-3} sodium sulphate (Meacac complex) as the eluent. Chromatography was carried out with a JASCO Tri Rotar V system at a flow-rate of 2.0 cm^3 min^{-1} (Clacac complex) or 1.0 cm^3 min^{-1} (Meacac complex) and the complexes were detected with a JASCO UVIDEC 100IV spectrophotometric detector at 312 nm (Clacac complex) or 307 nm (Meacac complex) where the two isomers [$\Delta(R)\Lambda(S)$ and $\Delta(S)\Lambda(R)$] give the same molar absorption coefficient. No detectable change in absorbance was observed during the epimerization reactions. The $\Delta(R)\Lambda(S)$ isomer was eluted faster in either complex. The areas of two bands on the chromatograms were determined by paper cut-outs matching the bands.

The kinetics of epimerization of [Co(acac)$_2$($C_6H_5NHCH_2CH_2NH_2$)]$^+$ (ref. 6) was studied by a similar way. A solution of $\Delta(R)\Lambda(S)$-[Co(acac)$_2$-($C_6H_5NHCH_2CH_2NH_2$)]Cl (*ca.* 10^{-3} mol dm^{-3}) in a phthalate buffer (pH 4.07, 4.77, and 5.22) was epimerized at 34°C. Portions of the reaction mixture were withdrawn at intervals and mixed with a small amount of dilute nitric acid, which served to stop effectively the epimerization reaction. The mixture was then chromatographed (column, 25 × 0.46 cm I.D.; eluent, 0.1 mol dm^{-3} sodium nitrate–0.03 mol dm^{-3} nitric acid; flow-rate, 2.0 cm^3 min^{-1}; sample volume, *ca.* 4 × 10^{-3} cm^3; detection wavelength, 340 nm).

RESULTS AND DISCUSSION

The selenium atom of free 2-(methylseleno)ethylamine ligand becomes chiral on coordination to a cobalt(III) ion. For [Co(Clacac or Meacac)$_2$-($CH_3SeCH_2CH_2NH_2$)]$^+$, two isomers (racemic pairs of the diastereomers) $\Delta(R)\Lambda(S)$ and $\Delta(S)\Lambda(R)$ are possible (Fig. 1). Such isomers are also possible for [Co(acac)$_2$($C_6H_5NHCH_2CH_2NH_2$)]$^+$. Each complex has been separated into its iso-

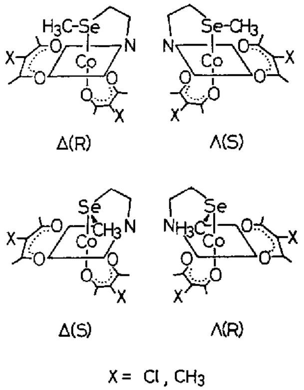

Fig. 1. The four stereoisomers of [Co(Clacac or Meacac)$_2$($CH_3SeCH_2CH_2NH_2$)]$^+$.

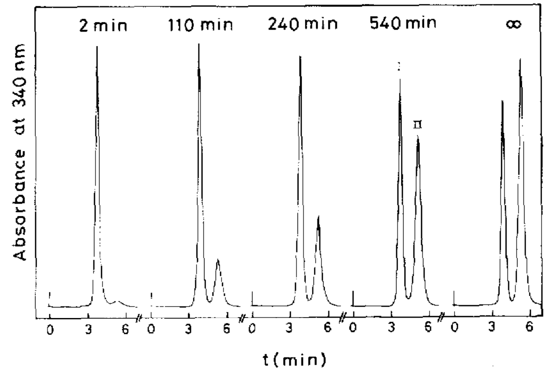

Fig. 2. Change in elution curve during the epimerization of Δ(*R*)Λ(*S*)-[Co(acac)$_2$(C$_6$H$_5$NHCH$_2$CH$_2$NH$_2$)]$^+$ at pH 4.07 and 34°C. Chromatographic conditions: column, 25 × 0.46 cm I.D.; eluent, 0.1 mol dm^{-3} sodium nitrate–0.03 mol dm^{-3} nitric acid; flow-rate, 2.0 cm^3 min^{-1}; UV detection, 340 nm.

mers by ordinary column chromatography and characterized by spectroscopy[5,6]. The selenide complexes isomerize in solution to give an equilibrium mixture of the isomers, and the isomerizations proceed by inversion at the selenium centres[5]. The isomerization of the diamine complex has been shown to take place by inversion at the secondary amine nitrogen atom, the reaction being catalysed by OH$^-$[6,7].

Kinetic studies of reversible isomerization (epimerization) between the two isomers of the present complexes were carried out by observing the change in chromatograms with reaction time. This method has the great advantages of a short elution time and micro amounts of samples[2,8]. Fig. 2 shows a typical set of elution curves obtained at intervals after Δ(*R*)Λ(*S*)-[Co(acac)$_2$(C$_6$H$_5$NHCH$_2$CH$_2$NH$_2$)]$^+$ had been dissolved in water at pH 4.07 and 34°C. The pseudo first-order rate con-

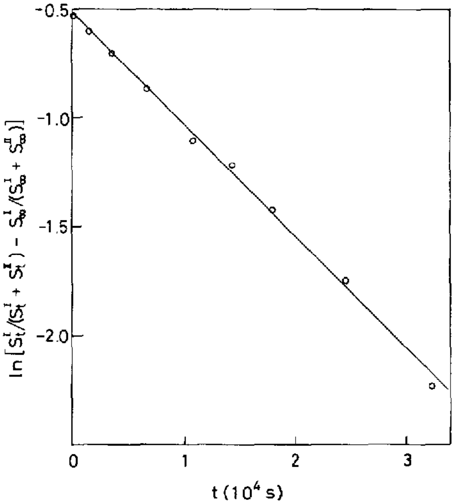

Fig. 3. The plots of ln[$S_t^I/(S_t^I + S_t^{II}) - S_\infty^I/(S_\infty^I + S_\infty^{II})$] *vs.* time for the epimerization of Δ(*R*)Λ(*S*)-[Co(acac)$_2$(C$_6$H$_5$NHCH$_2$CH$_2$NH$_2$)]$^+$ at pH 4.07 and 34°C (S_t^I, S_t^{II}, S_∞^I, and S_∞^{II} denote the areas of bands I and II at time *t* and at infinite time).

TABLE I

RATE CONSTANTS (k_{obsd} AND k_{ep}) FOR RACEMIZATION OF [Co(acac)$_2$-(C$_6$H$_5$NHCH$_2$CH$_2$NH$_2$)]$^+$ AT 34°C

pH	k_{obsd} *(s^{-1})*	k_{ep} *(mol^{-1} dm^3 s^{-1})*
5.22	$(7.49 \pm 0.07) \cdot 10^{-4}$	$(2.31 \pm 0.08) \cdot 10^5$
4.77	$(2.67 \pm 0.02) \cdot 10^{-4}$	$(2.35 \pm 0.07) \cdot 10^5$
4.07	$(5.14 \pm 0.03) \cdot 10^{-5}$	$(2.25 \pm 0.07) \cdot 10^5$

stant, k_{obsd}, was obtained by the method described previously (Fig. 3, Table I)[2]. The $k_{obsd}/[OH^-]$ (= k_{ep}) values are constant at 34°C in the pH range 4.07–5.22, indicating that the reaction is first order in [OH$^-$] (Table I). Thus, the rate law was the same as that obtained for racemization (epimerization) of other amine complexes such as [Co(NH$_3$)$_4$(CH$_3$NHCH$_2$CH$_2$NH$_2$)]$^{3+}$, $R = k_{ep}[\text{complex}][OH^-]$ (ref. 9). The runs starting from either of the isomers gave the same result within experimental error. From these observations, the reaction can be expressed as

$$\Delta(R)\Lambda(S) \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} \Delta(S)\Lambda(R)$$

The forward and reverse second-order rate constants, k_1 and k_{-1}, were obtained from k_{ep}($k_{ep} = k_1 + k_{-1}$) and the equilibrium constant, K_{eq} ($K_{eq} = k_1/k_{-1} = 1.68$). The average values of k_1 and k_{-1} are $(1.44 \pm 0.04) \cdot 10^5$ and $(0.86 \pm 0.03) \cdot 10^5$ mol^{-1} dm^3 s^{-1}, respectively. These values are *ca.* 10^6 times as large as those obtained for [Co(acac)$_2$(CH$_3$NHCH$_2$CH$_2$NH$_2$)]$^+$ at the same temperature[7].

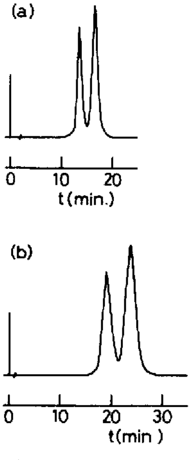

Fig. 4. The elution curves of [Co(Meacac)$_2$(CH$_3$SeCH$_2$CH$_2$NH$_2$)]$^+$ (a) and [Co(Clacac)$_2$-(CH$_3$SeCH$_2$CH$_2$NH$_2$)]$^+$ (b) equilibrated in 0.05 mol dm^{-3} sodium sulphate at 40°C. Chromatographic conditions: column, 7.5 × 0.75 cm I.D.; eluent, 0.025 mol dm^{-3} (Meacac complex) or 0.05 mol dm^{-3} sodium sulphate (Clacac complex); flow-rate, 1.0 cm^3 min^{-1} (Meacac complex) or 2.0 cm^3 min^{-1} (Clacac complex); UV detection, 307 nm (Meacac complex) or 312 nm (Clacac complex).

TABLE II

RATE CONSTANTS, k_{obsd}, k_1, AND k_{-1}, FOR EPIMERIZATION OF [Co(β-DIKETONATE)$_2$-(CH$_3$SeCH$_2$CH$_2$NH$_2$)]$^+$ (β-DIKETONATE = Clacac, Meacac, acac) IN 0.05 mol dm^{-3} SODIUM SULPHATE AT 40°C

$$\Delta(R)\Lambda(S) \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} \Delta(S)\Lambda(R), \qquad k_{\text{obsd}} = k_1 + k_{-1}$$

β-Diketonate	k_{obsd} (10^{-5} s^{-1})	k_1 (10^{-5} s^{-1})	k_{-1} (10^{-5} s^{-1})
Clacac	1.29 ± 0.05	0.80 ± 0.03	0.50 ± 0.03
Meacac	20.0 ± 0.3	12.1 ± 0.2	7.9 ± 0.2
acac*	3.39 ± 0.09	1.78 ± 0.06	1.61 ± 0.06

* From ref. 2.

The rates of epimerization for [Co(Clacac or Meacac)$_2$-(CH$_3$SeCH$_2$CH$_2$NH$_2$)]$^+$ were studied in the same way (Fig. 4). The K_{eq} values are 1.6 for the Clacac complex and 1.5 for the Meacac complex, and the values of k_1 and k_{-1} at 40°C are listed in Table II, together with those for [Co(acac)$_2$-(CH$_3$SeCH$_2$CH$_2$NH$_2$)]$^+$ at the same temperature[2]. The kinetics of the acac complex was studied by HPLC on SE-Toyopearl[2], however, relatively long elution time (90 min) was required. A column packed with a cation-exchanger derived from TSKgel G3000PW used in the present study seems to be superior to an SE-Toyopearl column. Two related complexes, the Clacac and Meacac complexes were separated into the isomers within 30 min (Fig. 4). Inversion at selenium of [Co(β-diketonate)$_2$(CH$_3$SeCH$_2$CH$_2$NH$_2$)]$^+$ at 40°C becomes faster in the order Clacac < acac < Meacac; an electronic effect induced by replacing the 3-hydrogen atom of acac with an electron-withdrawing chlorine atom or with an electron-releasing methyl group seems to affect the rate.

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