Molecular Design of Chelating Ligands with Highly Selective Recognition and Separation Functions for Group 13 Metal Ions (INTERFACE SCIENCE-Separation Chemistry)

Umetani, Shigeo; Le, Quyen T. H.; Matsui, Masakazu

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Kyoto University
Molecular Design of Chelating Ligands with Highly Selective Recognition and Separation Functions for Group 13 Metal Ions

Shigeo Umetani, Quyen T. H. Le and Masakazu Matsui

Studies on the solvent extraction with modified β-diketones such as α-phenylacetylacetone (PhAA) or α-phenybenzoylacetone (PhBA) revealed that the complexations of group 13 metal ions are strongly affected by the bite size (O-O distance in the chelate ring) and the interligand contact in the complex. The complexation of Al\(^{3+}\) was found to be under the effect of the interligand contact and that of In\(^{3+}\) the bite size. The appropriate substituents were introduced to β-diketone type ligands to control the bite size and the volume of the ligand.

Keywords: Solvent extraction / β-Diketone / Acylpyrazolone / Molecular recognition / Substituent effect / Bite size / Interligand contact

Highly selective ligands for group 13 metal ions (Al\(^{3+}\), Ga\(^{3+}\) and In\(^{3+}\)) have been successfully designed taking into consideration the bite size (O-O distance in the chelate ring) and the interligand contact in the complex. The complexation of Al\(^{3+}\) was found to be under the great influence of the interligand contact due to its remarkably small ionic radius. Al\(^{3+}\) is usually extracted better than In\(^{3+}\) owing to the smaller ionic radius, however, the opposite extraction order is seen for the extractants having bulk terminal substituents such as

\[
\begin{align*}
\text{HPMA} & : R = \text{CH}_3 \\
\text{HPMB} & : R = \text{Ph} \\
\text{HPM1NP} & : R = \text{1-Naph} \\
\text{HPM2NP} & : R = \text{2-Naph} \\
\text{HPMPIP} & : R = \text{O(CH\(_2\))}_3
\end{align*}
\]

In addition, the complexation of Al\(^{3+}\) was found to be under the great influence of the interligand contact due to its remarkably small ionic radius. Al\(^{3+}\) is usually extracted better than In\(^{3+}\) owing to the smaller ionic radius, however, the opposite extraction order is seen for the extractants having bulk terminal substituents such as

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\end{align*}
\]
dibenzoylmethane and thenoyltrifluoroacetone. Thus, the extraction of Al\(^{3+}\) is expected to be lowered by the bulky terminal substituents. Highly selective ligands for group 13 metals (Al\(^{3+}\), Ga\(^{3+}\), In\(^{3+}\)) have been successfully designed taking the two factors into consideration.

Five acylpyrazolone derivatives have been prepared as seen in the scheme. They are 1-phenyl-3-methyl-4-acetyl (HPMAP), -benzoyl (HPMBP), -(1-naphthoyl) (HPM1NP), -(2-naphthoyl) (HPM2NP), and -pivaloyl (HPMPiP) -pyrazolones. The O-O distances were estimated by the MNDO/H calculation, which is MNDO that takes into consideration the hydrogen bonding and has been found to be most suitable among the semi-empirical molecular orbital calculations to evaluate the structures of \(\beta\)-diketone type organic ligands [2]. The O-O distances of the acylpyrazolones except for HPMPiP are 2.60 - 2.65 Å, while that of HPMPiP is 2.46 Å. The 1H-NMR spectra show the evidence for the hydrogen bond strength. The signal assigned to the hydroxyl proton of HPMPiP appeared at \(d\) 14.9; whereas those for the other acylpyrazolones are too broad to observe at \(d\) 10-20. This signal did not move through changing the concentration (0.01 - 0.1 mol dm\(^{-3}\)) and was found to disappear after adding D\(_2\)O. It was reported that the hydrogen bonded enolic proton signal appears at that low magnetic field.

![Figure 1](image1.png)  
**Figure 1** Extraction of Al\(^{3+}\) (gray symbols), Ga\(^{3+}\) (solid symbols) and In\(^{3+}\) (blank symbols) into benzene with acylpyrazolones. [acylpyrazolone] \(_0\) = 5x10\(^{-3}\) mol dm\(^{-3}\) in benzene. [NaClO\(_4\)] = 0.1 mol dm\(^{-3}\).

The extractions of Al\(^{3+}\), In\(^{3+}\) and Ga\(^{3+}\) into benzene are shown in Fig.1 plotting the logarithmic value of the distribution ratio of metal ions (D) against pH. Being derived from the five membered heterocyclic 4-pyrazolone, the O-O distances of the present acylpyrazolone derivatives except for HPMPiP are longer than those of the conventional \(\beta\)-diketones. Owing to their long O-O distances, the extraction of In\(^{3+}\) was not disturbed and was made at pH 1-2. The extraction of Al\(^{3+}\) was seen in the higher pH region, although the ionic radius of Al\(^{3+}\) is much smaller than that of In\(^{3+}\). Considering that the acylpyrazolones themselves are bulky ligands and their acidities are quite similar, it is clear that the extraction of Al\(^{3+}\) is under the effect of the interligand contact. It was found that the extraction reduces as the substituent at the 4-position becomes bulkier. The quantitative separation of Al\(^{3+}\) from In\(^{3+}\) can be readily achieved with the naphthoylpyrazolones. The extraction of In\(^{3+}\) does not depend on the size of the substituents. The effect of the interligand contact is also seen in the extraction of Ga\(^{3+}\). While the ionic radius of Ga\(^{3+}\) is smaller than that of In\(^{3+}\), their extractions were similar. In addition, the extractability decreases as the substituents becomes bulkier like the case of Al\(^{3+}\). All of the acylpyrazolones examined are available to quantitatively separate Al\(^{3+}\) from Ga\(^{3+}\). Owing to the steric repulsion between the 4-pivaloyl and 3-methyl groups, the O-O distance of HPMPiP is narrowed and the extraction of In\(^{3+}\) came close to that of Al\(^{3+}\) as seen in Fig. 2, resulting in a quantitative separation of Ga\(^{3+}\) from Al\(^{3+}\) and In\(^{3+}\).

From our results so far, there are two factors governing the complexation of group 13 metal ions with \(\beta\)-diketones: the distance between the two donating oxygens and the interligand interaction, and their balance should decide the stability of each complex, that is, the extraction order, as well as the separation of Al\(^{3+}\) and In\(^{3+}\). This observation may contribute to the basic knowledge on organic ligands, especially on the concepts of their complexation with metal ions, and confirms our suggestion for a perspective strategy for designing novel ligands of high selectivity from well-known typical ones [2].

**References**