

Bibracchial diazatetralactams. Side-chain effects on cation binding and ionophoric properties

Bernard Cathala,^a Claude Picard,^{*a} Louis Cazaux,^a Pierre Tisnès^a and Claudius D'Silva^b

^a *Synthèse et Physicochimie Organique Unité associée au CNRS n°471, Université Paul Sabatier, 118 route de Narbonne, 31062 Toulouse, France*

^b *Department of Chemistry, Manchester Metropolitan University, Faculty of Science and Engineering, John Dalton Building, Chester Street, Manchester, UK M1 5GD*

The formation constants in THF solutions of calcium complexes diazatetralactams bearing two side-chains were found in the range $4.6 < \log \beta_{ML} < 8.2$ and follow the substituent sequence $\text{Boc} < \text{Me} \sim \text{CH}_2\text{CO}_2\text{Me} < \text{CH}_2\text{CONMe}_2 < \text{CH}_2\text{Py}$. This side-chain effect was again observed in liquid–liquid extraction studies either with calcium or zinc picrates. Efficient zinc extraction constitutes the main difference with the dioxatetralactam series. The metallic ion transport across a chloroformic membrane studied with the pyridine derivative agrees well with extraction data. Specific ionophoric properties were evidenced with ion-selective electrodes.

Natural ionophores possess selective complexing properties and act as carriers capable of crossing the hydrophobic layer of lipids and lipoproteins which form the structure of membranes. Among these compounds, macrocyclic depsipeptides like enniatins¹ or valinomycin^{2,1b} (Scheme 1) exhibit good K^+ selectivity. Whilst alamethicin,³ a side-armed macrocyclic heptadecapeptide, has antibacterial and ionophoric activities; it also forms ion channels (Ca^{2+} , Mn^{2+} ...) in chromaffin cell plasma membranes.

Bibracchial lariat ethers⁴ such as the diaza-18-crown-6 derivatives **3a–d**^{4,5} have enhanced complexing ability with respect to simple crown ethers and display dynamic binding properties greater than cryptands.

In this paper, we report the binding and ionophoric properties of some 18-membered bibracchial diazatetralactams **2c–e** (Scheme 2) substituted with appropriate side-arms ($\text{R} = \text{CH}_2\text{CO}_2\text{Me}$, $\text{CH}_2\text{CONMe}_2$, CH_2Py).

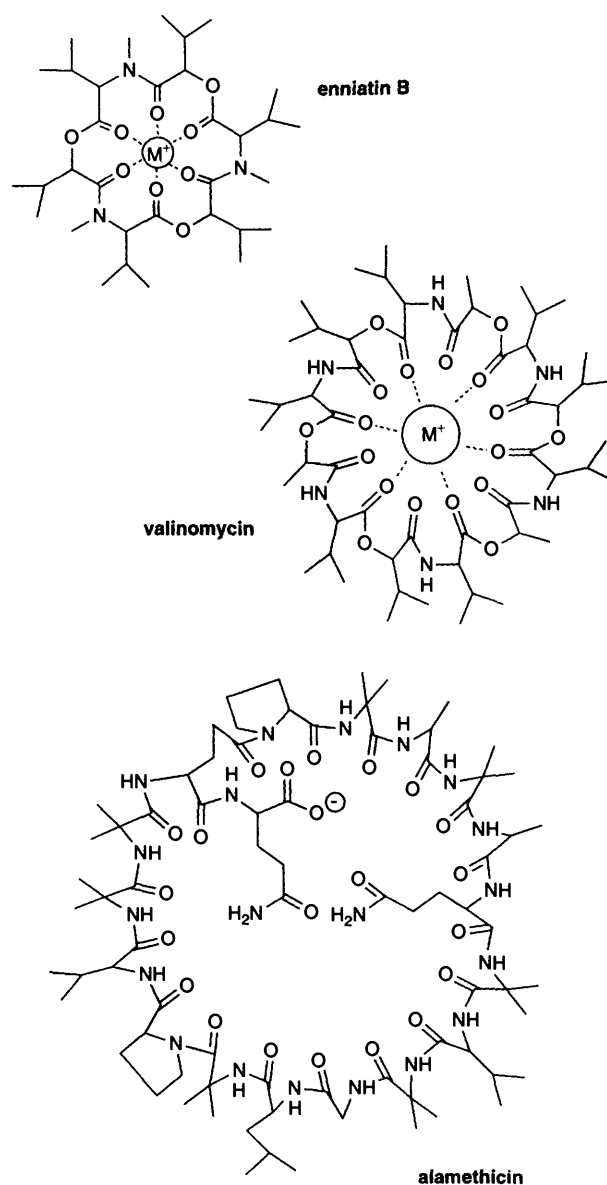
These diazatetralactams^{6a} are related to dioxatetralactam **1a** which is selective as other dioxatetralactams⁷ for alkaline-earth cations *vs.* alkaline, Mg^{2+} and Zn^{2+} ions. In addition, the four benzyl substituents provide a hydrophobic environment necessary for good transport across membranes. The other compounds **2a** ($\text{R} = \text{CO}_2\text{Bu}^t$) and **2b** ($\text{R} = \text{Me}$) complete the series or allow a direct comparison ($\text{R} = \text{Me}$) with the dioxatetralactam series.

Results and discussion

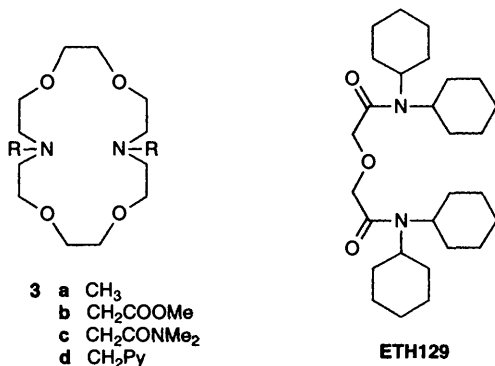
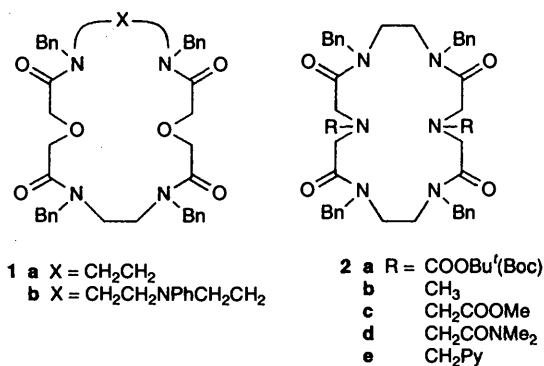
Four aspects of the complexing properties of bibracchial diazatetralactams toward a selection of metal cations (Na^+ , K^+ , Mg^{2+} , Ca^{2+} , Zn^{2+}) were examined. Firstly, the stoichiometry and the formation constants of five Ca^{2+} complexes in THF, then the ionophoric selectivities by liquid–liquid extraction and transport through a chloroformic or polymeric membrane.

Binding constant determinations

The formation constants of the Ca^{2+} complexes were measured in tetrahydrofuran solutions by UV spectrophotometry using the picrate ion absorbances. The ability of ligands **2** to separate ion pairs in a solvent of low polarity (THF) is illustrated in Fig. 1. For instance, addition of variable amounts of **2e** to a 3.23×10^{-5} M THF solution of CaPic_2 causes a bathochromic shift of the absorption maximum from 333 to 350 nm. This shift occurs in low polarity media when contact ion pairs are converted



Scheme 1



Scheme 2

more or less into ligand separated ion pairs. Such changes have been previously used for the spectrophotometric determination of binding constants between metallic picrates and crown-ethers,⁸ calixarenes⁹ or tetralactams.⁷ The number of species which are involved in the two types of experiments ($0 < \rho \leq 1$ and $0 < \rho \leq 10-17$ with $\rho = [\text{ligand}]/[\text{cation}]$) is calculated by factorial analysis of the matrix of absorbances using the STAR/FA program¹⁰ and by the observation of isobestic points (Table 1). In all the cases except for **2a** three absorbing species, *i.e.* two complexes, are noticed for $\rho = 0 \rightarrow 1$ and four absorbing species *i.e.* three complexes for $\rho = 0 \rightarrow 10-17$. In the case of **2a**, only one complex is in the $0 < \rho < 10$ range. The observed isobestic points, *e.g.* 337 ($0 < \rho < 1$), 350 ($2 < \rho < 13$), 375 ($0 < \rho < 0.5$), 404 nm ($0.5 < \rho < 1$) for **2e**, are compatible with these results and with the existence of three complexes.

$$\text{ML}, \log \beta_1 = \frac{[\text{ML}]}{[\text{M}][\text{L}]}; \quad \text{M}_2\text{L}, \log \beta_2 = \frac{[\text{M}_2\text{L}]}{[\text{M}]^2[\text{L}]};$$

$$\text{ML}_2, \log \beta_3 = \frac{[\text{ML}_2]}{[\text{M}][\text{L}]^2}$$

The treatment of the experimental data following this model using the STAR program¹⁰ confirms these features (Table 1).

The Ca²⁺ complex formed with **2a** is exclusively of the 1:1 ML stoichiometry with the smallest formation constant ($\log \beta = 4.6$). In the other cases two species (ML, M₂L) for $\rho \leq 1$ and three species (ML, M₂L, ML₂) for $\rho > 1$ are observed. It is worth noting a good agreement of stability constants between the two sets of experiments ($\rho \leq 1$ and $\rho \leq 17$). An initial conclusion can be drawn from Table 1: that there is a stabilization of the calcium complexes in the sequence CO₂Bu^t < CH₂CO₂Me ~ Me < CH₂CONMe₂ < CH₂Py. In all the cases (except **2a**) the formation constants are greater than that found for the dioxatetralactam **1a**/Ca²⁺ complex. However, for diazatetralactams **2b**, **2c**, $\log \beta_1$ are comparable to that of **1a**, but $\log \beta_2$ has a higher value (+2.2 and +3.6 log units) indicating a more stable M₂L complex.

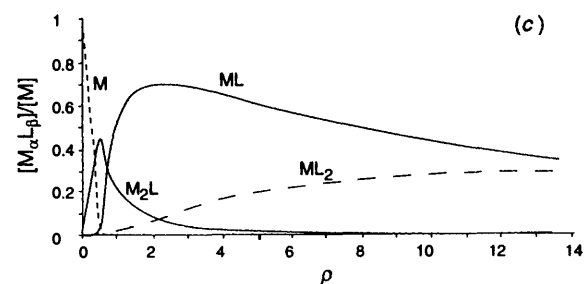
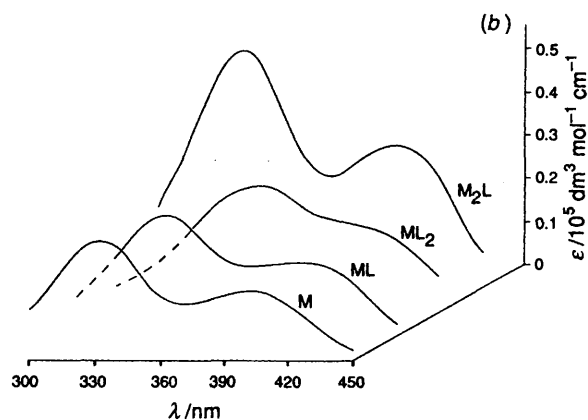
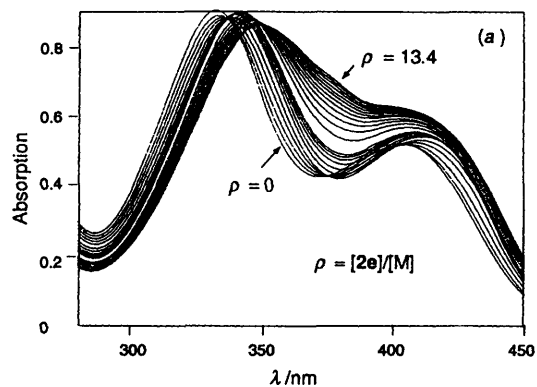


Fig. 1 (a) Absorbances at 25 °C of solutions of calcium picrates (3.23×10^{-5} M in THF) corrected by dilution factors for different ratio $\rho = [2e]/[M]$; (b) spectra of pure species (M, ML, ML₂, M₂L) after calculation with the STAR program; (c) species distribution against ρ

The bathochromic shifts of the picrate band (Table 1) are also indicative of the complexation strength. These shifts are related to the change of a tight ion pair to a looser ion pair.^{8b} Two types of ligands can be distinguished from the higher energy band (336–350 nm). Compounds **2a** and **2b** display a weak bathochromic shift (3 and 4 nm) for the ML complex while ligands **2c–e** bearing CH₂-X bibrachial functionalities present enhanced shifts (9–17 nm). The differentiation of bathochromic shifts is not clearly observed for the high wavelength transition band (403–405 nm). Thus, there is a loose ion-pair interaction, probably related to the steric hindrance of these bibrachial groups. The greatest shift is observed for the pyridinic derivative **2e** at 350 nm. Nevertheless, none of these wavelengths reach the 380 nm value for a completely separated ion-pair. However, this value is almost obtained for the ML₂ complex derived from the **2e** pyridinic ligand. Thus, the general trend is that the picrate anions take part in the complexation of calcium ions.

The high formation constants for the amide and pyridine side-arms are in agreement with previous results on crown-ethers.^{11,5a}

Table 1 Formation constants,^a absorption maxima^b and molar absorptivities^c of the Ca²⁺ complexes

Compd.	R		ML	M ₂ L	ML ₂
2a	CO ₂ Bu ^t (Boc)	log β	4.6	—	—
		λ _{max}	336 (3); 405 (5)	—	—
		ε _{max}	27 300; 15 200	—	—
2b	Me	log β	6.0	11.6	9.9
		λ _{max}	337 (4); 405 (5)	335 (2); 410 (10)	345 (12)
		ε _{max}	29 800; 17 500	59 800; 36 000	27 500
2c	CH ₂ CO ₂ Me	log β	5.9	10.2	9.0
		λ _{max}	342 (9); 405 (5)	340 (7); 414 (14)	365 (32)
		ε _{max}	28 600; 17 000	55 500; 33 600	32 000
2d	CH ₂ CONMe ₂	log β	7.6	14.0	12.3
		λ _{max}	345 (12)	342 (9); 410 (10)	370 (37)
		ε _{max}	30 800	61 600; 35 700	37 600
2e	CH ₂ Py	log β	8.2	15.6	11.7
		λ _{max}	350 (17)	340 (7); 410 (10)	375 (42)
		ε _{max}	28 900	55 100; 32 800	31 300
1a		log β	5.6	8.0	—

^a Formation constants β(ML) in 1 mol⁻¹, β(M₂L) and β(ML₂) in 1² mol⁻² in THF at 25 °C. Uncertainties on β values are around 10%. All the statistical tests are positive. ^b λ_{max}(nm); between brackets: bathochromic shifts vs. calcium picrate (333 nm, 27 750 and 400 nm, 15 900). ^c ε_{max}(1 mol⁻¹ cm⁻¹).

Table 2 Extraction percentages^a (E%) for tetralactams **1** and **2** and ETH129 with different metallic picrates in CHCl₃ at 25 °C

Compd.	R	-Log P ^b	Cation (r/Å)					$\frac{E_{Ca^{2+}}}{E_{Na^{2+}}}$	$\frac{E_{Ca^{2+}}}{E_{K^+}}$	$\frac{E_{Ca^{2+}}}{E_{Mg^{2+}}}$	$\frac{E_{Ca^{2+}}}{E_{Zn^{2+}}}$
			Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	Zn ²⁺				
			(0.98)	(1.33)	(0.78)	(1.06)	(0.74)				
1a ^c		3.8	6	6	4	77	1	13	12	17	> 100
1b ^c		5.2	≤ 1	< 1	2.5	88	4	> 100	> 100	35.2	22
2a	CO ₂ Bu ^t (Boc)	4.0	≤ 1	≤ 1	≤ 1	≤ 1	≤ 1	—	—	—	—
2b	CH ₃	6.6	8	≤ 1	NR ^d	44	74	5.5	> 100	—	0.6
2c	CH ₂ CO ₂ Me	3.7	≤ 1	≤ 1	≤ 1	44	50	> 100	> 100	> 100	0.88
2d	CH ₂ CON(Me) ₂	6.5	18	12	21	85	91	4.7	7	4	0.93
2e	CH ₂ Py	5.6	20	15	11	95	99	4.75	6.3	8.6	0.95
3d ^c	CH ₂ Py	—	47	59	≤ 3	6	9	0.1	0.1	> 2	0.7
ETH129 ^c		6.7	0	1	5.5	53	40	> 100	50	10	1.3

^a Extraction conditions: temperature 25.0 ± 0.2 °C; aqueous phase (0.25 ml): [picrate] = 1.5 × 10⁻² M; organic phase (CHCl₃, 0.25 ml): [ligand] = 1.5 × 10⁻² M. ^b Lipophilicity measured by RPTLC technique. ^c Ref. 7. ^d NR: unreproducible results. ^e CH₂Cl₂, metallic perchlorates, ref. 5.

Ionophoric properties

(a) **Liquid-liquid extractions.** The cation-binding and ionophoric abilities of the bibracchial diazatetralactams were examined by chloroformic extraction of alkali-metal (Na⁺, K⁺), alkaline-earth (Ca²⁺, Mg²⁺) and Zn²⁺ picrates from an aqueous phase (Cram method). The extraction percentages (E%) are given in Table 2 with the Ca²⁺ selectivities and the lipophilicities of the five ionophores and four reference compounds.

The Boc-derivative **2a** does not extract cations probably due to the presence of bulky *tert*-butyl groups.

From the results observed for the methyl-derivative **2b** and the reference dioxa compound **1a**,⁷ it appears that **2b** has a higher capability for zinc extraction (74 vs. 1%) but a lesser one for calcium extraction (44 vs. 77%).

The calcium extraction increases following the sequence CO₂Bu^t < Me ~ CH₂CO₂Me < CH₂CONMe₂ < CH₂Py. Thus, the nature of the side-arm is very important for calcium extraction. However, if the amide function improves extraction in agreement with the HSAB theory,¹² the result with the pyridinic function is surprising in relation to this theory. Tsukube demonstrated⁵ that pyridinic groups do not possess a great affinity for calcium ions but (see compound **3d**, Table 2) could be a good complexation auxiliary with macrocycles possessing hard-base type atoms like crown ethers.

The other remarkable trend is the lack of selectivity vs. the zinc cation in contrast with the dioxatetralactams **1a** and **1b**. All the diazatetralactams (excepted **2a**) extract the zinc ion, and even **2d** and **2e** do so to a great extent. A slight extraction of the alkaline metal ions and the magnesium cation is also noticed.

The results from Table 2 give the general affinity order Zn²⁺ ~ Ca²⁺ > Na⁺ ~ K⁺ ~ Mg²⁺ for the diazatetralactams vs. the studied cations. Table 2 also contains the extraction selectivities of the calcium ion relative to those of the reference compounds **1a**, **1b** and ETH129.⁷ These values show that the methyl ester derivative **2c** possesses the best selectivities (> 100) for the calcium ion vs. alkali-metal and magnesium ions. The selectivity vs. the zinc ion remains comparable to that of the non-cyclic compound ETH129 but smaller than that of the dioxatetralactam **1a**. No selectivity was observed with respect to cation size as observed for the dioxatetralactams. IR spectroscopy results showed that carbonyl amide stretching bands of **2** are shifted toward lower frequency (Δν ~ 20 cm⁻¹) upon complexation. This effect can be associated to the chelation of Ca²⁺ cation at the same time by all the amide groups of the macrocycle. On the other hand, in a structural study¹³ of 18-membered dioxatetralactams we have shown that the cation cannot be included inside the cavity of the macrocycle as the amide functions are unable to converge toward the centre of the cavity. These amide groups point toward the cation outside the mean-plane of the macroring. A same structural behaviour is proposed for the complexes with diazatetralactams† and may explain this lack of cation size selectivity.

† In a subsequent publication these findings will be emphasized for complexes **2d**/Ca²⁺ and **2e**/Ca²⁺ with the participation in the complexation of the amide oxygens and the pyridinic nitrogens on the side arm by using ¹H, ¹³C NMR, IR and molecular modelling techniques.

Table 3 Transport rates $\times 10^6$ (mol h⁻¹)^a

Carrier	R	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	Zn ²⁺
2e	CH ₂ Py	0.5	0.6	1.0	5.8 29.9 ^b	10.9
3d^c	CH ₂ Py	10.5	7.9	≤0.3	11.5	4.1

^a Transport conditions: aqueous phase I: 11 ml, guest picrate, $c_1 = 1.2 \times 10^{-3}$ M; CHCl₃ phase: 11 ml, host carrier, $c_2 = 1.2 \times 10^{-3}$ M; aqueous phase II: 11 ml. ^b $c_1 = c_2 = 1.94 \times 10^{-3}$ M. ^c Aqueous phase I: 5 ml, guest perchlorate, $c_1 = 0.5$ M; CH₂Cl₂ phase: 12 ml **3d**, $c_2 = 0.0372$ M; aqueous phase II, 5 ml; ref. 5.

Table 4 Potentiometric selectivity coefficients^a log $K_{Ca,M}^{Pot}$

Ionophore	R	Li ⁺	Na ⁺	K ⁺	Mg ²⁺	Zn ²⁺
2a	Boc	-2.2	-2.4	-2.0	-3.6	-2.4
2b	Me	-2.5	-2.4	-1.9	-3.1	-2.1
2d	CH ₂ CONMe ₂	-3.0	-2.5	-2.1	-3.0	-2.6
2e	CH ₂ Py	-2.3	-2.1	-1.7	-3.2	-2.4
1b^b		-3.0	-2.4	-2.0	-3.7	-3.0
ETH129 ^b		-2.5	-2.7	-2.1	-4.3	-2.5

^a Membrane solvent: *o*-NPOE. Incorporated lipophilic anionic sites: KTpCIPB. Fixed interference method. ^b Ref. 19.

The main conclusions of that study are as follows. (i) The replacement of an oxygen atom by a substituted nitrogen atom in the backbone of the tetralactam ring deeply modifies the extraction properties, namely a decrease by half of the extraction of the calcium ion and a considerable increase of the extraction of the zinc ion. The amine or pyridinic nitrogen atoms present good affinities to co-ordinate the zinc cation.¹⁴ For compound **2b** (R = Me) the two pivot nitrogen atoms can probably participate in the complexation, while for **2c** (R = CH₂CO₂Me), **2d** (R = CH₂CONMe₂) and **2e** (R = CH₂Py) the lateral chain containing basic sites can be preferentially involved in the chelation of the cation in a sequence following roughly the basicity of the donor atoms **2e** > **2d** > **2c**. (ii) The bibracchial groups introduce a variety of extraction trends (side-arm effects). The Boc group (**2a**) extracts none of the studied cations. The methyl ester group (**2c**) gives the best calcium selectivity *vs.* other ions, but the smallest extraction of calcium ions. On the other hand, the pyridine (**2e**) and dimethyl carboxamide (**2d**) groups play a great role in calcium extraction and zinc extraction, but lead to poor selectivities.

(b) **Cation transport across a liquid membrane.** The separation of molecules and ions by membranes is of broad interest.¹⁵ With dilariat diazatetralactams as synthetic ionophores transport experiments were performed in a CHCl₃ liquid membrane system. Table 3 summarizes the transport properties of the pyridinic diazatetralactam **2e**, compared to the pyridine-functionalized diaza 18-crown-6 **3d**. The transport rates of **2e** follow roughly¹⁶ the extraction percentages: Zn²⁺ > Ca²⁺ > Mg²⁺ ~ Na⁺ ~ K⁺. But as previously noticed by Tsukube^{5b} the guest selectivity of transport is somewhat different from that of the extraction process. Calcium ions with the diazatetralactams are extracted to the same great extent as Zn²⁺ ion but are less efficiently transported. On the other hand, the doubly-armed pyridine crown ether **3d**, which is selective for alkaline ions in the extraction process, shows the following sequence^{5b} in transport experiments: Ca²⁺ > Na⁺ > K⁺ > Zn²⁺ ≫ Mg²⁺. The CH₂Py side-arm effect increases the calcium and zinc transport rates in the diaza crown ether **3d** where the four oxygen atoms in the ring induce a great ability to carry the alkaline ions.

The replacement of the oxygen atoms of the ether-type by amide functions (**2e** *vs.* **3d**) greatly reduces alkali-metal selectivity and inverts the Ca²⁺/Zn²⁺ ratio; this inversion is probably due to the larger size of the Ca²⁺ ion ($r = 1.0$ Å),

which is more easily incorporated into a crown ether ring; the smaller Zn²⁺ ion ($r = 0.74$ Å) is better adapted to the reduced cavity formed by the diazatetralactam ring with its four amide oxygens and its pyridinic arms directed toward the ion outside the ring mean plane.

(c) **Ion-selective electrodes.** Ion-selective electrodes (ISE) based on ionophore impregnated polymeric membranes are increasingly being used for analytical purposes,¹⁷ but selectivity and detection limits need to be improved. Calcium-selective electrodes are of particular interest, *e.g.* for free calcium determinations.¹⁸ As a matter of fact, several neutral ionophores have been especially developed for this type of ISE: ETH1001,¹⁹ ETH129,²⁰ ETH5234.²¹ Recently, we reported the ionophoric properties of a dioxatetralactam series.²² The six studied ionophores including **1b** proved to be very good Ca²⁺ neutral carriers displaying good discrimination against Mg²⁺ and alkali-metal cations with Nernstian and near-Nernstian responses to these ions in the range 10⁻⁵–10⁻¹ mol dm⁻³. The fixed interference method was used to determine relative selectivity coefficients with potassium tetrakis(*p*-chlorophenyl)borate as a resistance modifier and 2-nitrophenyl octyl ether as a plasticizer. The same conditions were used for the diazatetralactam series and the results are collected in Table 4. The selectivity coefficients $K_{Ca,M}^{Pot}$ show a high selectivity for Ca²⁺ ions *vs.* Li⁺, Na⁺, K⁺, Mg²⁺ and Zn²⁺.

The similar behaviour of the four diazatetralactams tested in this study show that the effect of the side-arms seems more or less secondary compared to the potentiometric selectivity introduced by the tetralactam ring. For instance, the amide arm does not bring any additional selectivity by comparison with the dioxatetralactam **1b** while in the diaza crown ether series²³ the amide arm is very effective.

Accordingly to Ammann,²⁴ the main parameters determining the selectivity of a neutral carrier based membrane electrode are the stability constants of the carrier/ion complex in water, the extraction properties of the membrane phase and the concentration of the free carrier. For the Boc derivative **2a**, it is meaningful to note that the very weak metal extraction in CHCl₃ (≤1%) cannot be correlated with the $K_{Ca,M}^{Pot}$ results. As this compound gives a reasonable stability constant in THF (log $\beta = 4.6$) for the calcium metal ion, we make the assumption that the permselectivity of the neutral carrier membrane explains the difference with the chloroformic membrane.

Conclusions

The studied bibracchial diazatetralactams can be characterized on the basis of a side-arm effect for their complexing abilities and for most of their ionophoric properties. This effect appears especially in calcium complex formation constants which are significantly increased depending on the nature of the arm: Boc < Me ~ CH₂CO₂Me < CH₂CONMe₂ < CH₂Py. Examination of the ionophoric properties gives more diverse results. The calcium and zinc metal ions are readily extracted compared with alkali and magnesium ions for the amide—and pyridine—armed derivatives. The Boc derivative is ineffective whatever the cation whereas the methyl and ester derivatives give intermediate results with higher selectivities. A main difference with the dioxatetralactams is the high percentage of zinc ion extracted. The values of the transport ratio through a chloroformic membrane follow roughly the extraction percentages. The amide and pyridine arms form certainly the best encapsulated complexes which lead to better ionophoric properties. However, the potentiometric selectivity coefficients do not vary very much from one derivative to the other. In each case the value is high and compares well with those of dioxatetralactams and the known ETH129. The side-arm effect here is inoperative, the main effect being due to the lactamic functions of the ring. The transport through a polymeric membrane is thus very specific and the potentiometric ion

selectivity of the carrier based electrodes cannot be easily correlated with cation extraction and transport properties through a chloroformic membrane.

Experimental

UV-VIS spectra were monitored on a Perkin-Elmer Lambda 17 spectrophotometer. Compounds **2a-e** were obtained as reported in ref. 6.

Determination of formation constants

The formation constants for ion-ligand complexes were determined by UV spectrophotometry in tetrahydrofuran solutions following Smid.^{8b} As shown in Fig. 1 the sequential addition of aliquots of a ligand to a 3×10^{-5} M solution of calcium picrate in THF ($\rho = \text{ligand/salt} = 0 \rightarrow 10^{-17}$) induces large spectral changes in the wavelength range 280–450 nm. The calculation method uses the STAR/FA and the STAR programs developed by Beltran¹⁰ for studying ionic equilibria from spectrophotometric data. STAR is a non-linear regression program for the refinement of complex formation constants. The mass balance equations of the system were solved from the given model, the total concentration of the components and the pH of the solution. STAR gives several statistical characteristic parameters to test the reliability of the regression process. The most important parameter is the standard deviation of the absorbances (A) which must be compared to the instrumental error of the spectrophotometer ~ 0.002 ; an acceptable fit is $S(A) < 0.005$. Other parameters: the distribution of residuals is examined by the Skewness, Kurtosis and Pearson's χ^2 tests; for a Gaussian distribution these values should be equal to 0.3 and < 12.6 (for six degrees of freedom at the 95% confidence level) respectively. The Hamilton R factor (%) indicates the relative fit ($\leq 1\%$). The STAR/FA program is used to determine the number of absorbing species in solution by factor analysis of the absorbance data matrix.

Lipophilicity determination

Lipophilicities of the ligands were determined by their TLC retention R_F according to ref. 25. The TLC system is calibrated with a set of reference compounds of known lipophilicities with detection at 254 nm.²⁶ TLC was performed with Macherey-Nagel Sil RP18W reversed-phase plates and the solvent system used consisted of methanol-water (75–25 by volume).

Extraction experiments

These were carried out by adding a CHCl_3 solution of diazatetralactam (0.015 M, 0.25 ml) to an aqueous solution of metal picrate (0.015 M, 0.25 ml). After stirring the mixture for 15 h, the aqueous phase was separated and the percent of picrate salt extracted ($E\%$) was determined by UV spectrophotometry as previously related.⁷

Transport experiments

These were performed at 25 °C in a new apparatus which will be described later in a full paper. The used cell is divided in three parts of 11 ml each separated by two Fluoropore membranes of 175 μm thickness and stirred independently and synchronously at 550 rpm. The ionophore, dissolved in CHCl_3 , was placed in the middle compartment and the two aqueous phases were placed in the other parts. The transport rates gathered in Table 3 were calculated from the quantity of ion transported after 23 h in the aqueous phase II, which was determined by UV spectrophotometry at the maximum absorbance of the picrate ion ($\lambda_{\text{max}} = 355$ nm, $\epsilon = 14\,500$ and $29\,000$ $\text{cm}^{-1} \text{M}^{-1}$ respectively for M^+ and M^{2+} ions).

Electrode preparation and EMF measurements

Ion-selective electrode membranes of the PVC matrix type were prepared according to a previously reported procedure.²²

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