Lipid-Catalyzed Transport of Cu(II) through Liquid Membranes

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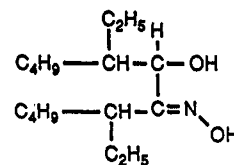
Six long-chained ligands were synthesized and examined for their ability to transport Cu(II) through a liquid membrane. The transport was proton-driven and capable of moving metal ions "up-hill". The time-dependence of the Cu(II) concentrations was determined for each carrier and for all three phases of the liquid membrane system. Thus, it was possible to follow the transfer of Cu(II) from the aqueous source phase to the organic layer and from the organic layer to the aqueous receiving phase. In addition, relative partitioning equilibria of Cu(II) between the organic layer and the aqueous phases were compared. It was found that all transport rates were kinetically controlled. Of the six carriers, only one was truly effective (the others experiencing difficulties releasing Cu(II) into the receiving phase). This one carrier displayed a remarkable activity exceeding that of LIX63 (a "standard" in industrial extractions from copper ore). The activity was attributed to the carrier bearing polar hydroxyls at the ligand end of molecule, thereby enhancing the affinity for the organic/water interface where the rate-determining reactions take place. Studies were carried out varying the pH of the aqueous phases, the carrier concentration, and the nature of the organic layer.

Introduction

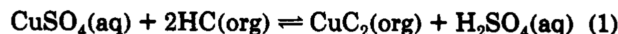
One particular type of "liquid membrane" consists of an organic solvent (often chloroform) lying at the bottom of a U-tube. In each arm of the U-tube a water layer floats on the chloroform. This simple device has been widely used to study ion transport from one water compartment to the other, a process requiring, of course, passage through the chloroform barrier.[1-3] We describe herein the synthesis of a new lipid compound that serves as a highly effective transporting agent of Cu(II) through liquid membranes.

In terms of Webster's definition of a membrane (a "thin, soft, pliable sheet or layer"), a liquid membrane is in fact not a membrane at all. A liquid membrane is merely bulk chloroform and, as we have amply demonstrated,[4] its similarity to biological membranes, where molecules are organized,[5] is tenuous. Nonetheless, liquid membrane studies are useful for assessing partitioning of metals into and out of organic phases, a subject of considerable importance in medicine,[6] water purification,[7] and metallurgy.[8]

Copper is commonly removed from ore by solvent extraction routes utilizing hydroxyoxime-type carriers. One such carrier, LIX63 (drawn below), has become a "standard" in the industry.[9,10] Plants in Chuquicamat (Chile), Chinggola (Zambia), and Twin Buttes (U.S.) have employed these materials.[11] The copper isolation is based on eq 1 where "HC" represents a hydroxyoxime carrier.



LIX63



$$CuSO_4(aq) + 2HC(org) \rightleftharpoons CuC_2(org) + H_2SO_4(aq) \quad (1)$$

Note that eq 1 is reversible, thereby allowing the following purification scheme: (a) Copper salts are leached from crushed ore into weakly acidic water; (b) Cu(II) is extracted into an organic solvent containing LIX63: and (c) strongly acidic water is then used to extract Cu(II) back into the aqueous phase where subsequent electrolysis provides the free metal.

The above sequence is simulated in part by the liquid membrane setup shown in Figure 1. Thus, Cu(II) was placed in an aqueous source phase buffered at pH = 4.63. One of the lipid carriers listed in Figure 2 was dissolved in a stirred chloroform "membrane". The carrier transferred ions from the source phase to the chloroform. The Cu(II) complex, upon coming into contract with the aqueous receiving phase of pH = 1.0, released its metal ion into the water. In other words, carrier shuttled ion from one aqueous compartment to the other, the whole process being driven by the pH differential.[12] Even at >50% transfer, when the receiving compartment had a higher Cu(II) concentration than the donating one, ion was effectively relocated.

The vast majority of liquid membrane studies in the past have monitored the ion content of only the receiving

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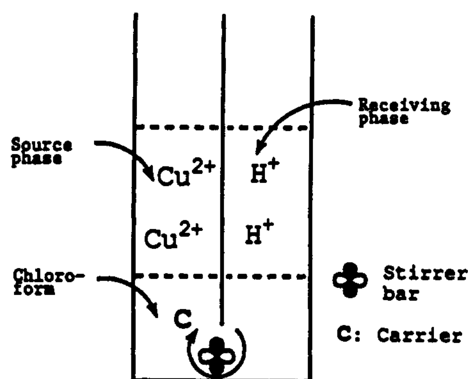

Figure 1. Liquid membrane apparatus used in experiments. See text for details.

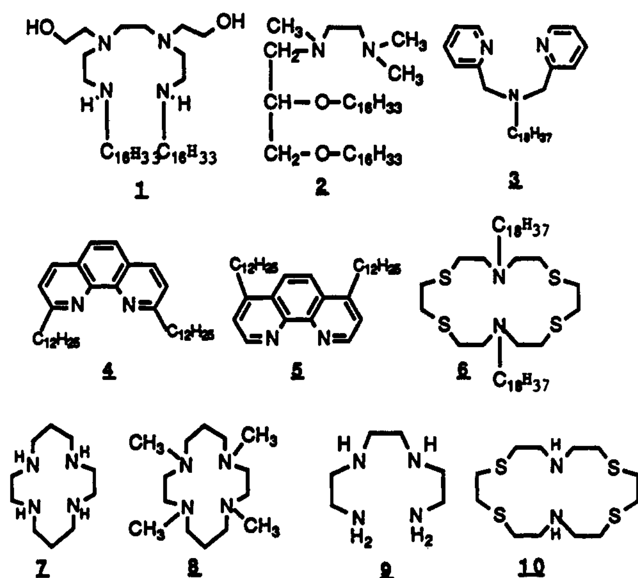

Figure 2. Carriers in addition to LIX63 used in experiments. Syntheses of carriers 1–6 are described in the Experimental Section.

phase. In so doing, however, valuable mechanistic information was lost. A slow ion transfer, for example, could signify a carrier's inability to extract ions from the source phase into the chloroform. Alternatively, a slow tranfer could reflect a problem in release of ions into the receiving phase. Only by assessing the Cu(II) content of all three phases, as we have done herein, can the two possibilities be differentiated.

A good carrier must be chloroform soluble in its free and complexed forms. Attachment of hydrocarbon tails seemed the easiest way of imparting organic solubility to metal complexes. Thus, six of the 10 compounds in Figure 2 possess lipoidal character.[13] Four compounds without tails were included for comparison purposes.

One of our goals was to find a carrier superior to those in the literature including LIX63.[14-19] Initially, we had on hand little guidance by way of information relating transport efficiency to carrier structure. Only through good fortune[20] (since our compounds were selected more-or-less arbitrarily) was the goal ultimately achieved. More importantly, however, our data helped define the factors that control ion transport in liquid membranes.

Table I. Copper(II) (%) Transported through the Chloroform Phase after 10 h[a-c]

carrier	% Cu(II) transported (receiving phase)	% Cu(II) remaining (source phase)
1	78.8	10.4
2	5.2	63.7
3	0	51.5
4	0.10	85.8
5	0.11	55.0
6	0.26	91.4
LIX63	31.5	61.1

[a] Source phase: 8.0 mL of 5.0 mM $CuSO_4$, pH = 4.63 acetate buffer. Receiving-phase: 8.0 mL, pH = 1.0 (HCl). Liquid membrane: 20 mL of chloroform, 1.0 mM carrier. See text for further details. [b] Numbers in table refer to percent of original copper in the source phase ending up in the aqueous receiving phase or remaining in the aqueous source phase. [c] Data represent average of three runs differing from one another by less than 5%.

Results

Transport experiments were carried out using a liquid membrane system (Figure 1) containing a source phase (8.0 mL, 5.0 mM $CuSO_4$, pH = 4.63), a chloroform layer (20 mL, 1.0 mM carrier), and a receiving phase (8.0 mL, pH = 1.0). A single apparatus and a constant stirring speed at 25 ± 0.5 °C were used throughout. The pH values of the aqueous compartments were selected for their similarity to large-scale operations.[11] Cu(II) concentrations in the aqueous compartments were monitored as a function of time by means of a colorimetric method (see Experimental Section). Reported data represent averages of at least three runs that generally differed by less than 5%.

Table I lists the percent of Cu(II) transported, under standard conditions, from the source phase to the receiving phase in a 10-h time span. Carrier 1 of Figure 2 is seen to deliver 79% of the Cu(II) ion compared to only 34% for the next best, LIX63. All the other lipid carriers in Figure 2 were ineffective (i.e., ≤5% in the receiving phase). It thus became necessary to determine exactly why the lipid carriers behaved so differently. In this connection, even the test data in Table I reveal useful information. Carrier 3, for example, obviously retains a large quantity of Cu(II) within the chloroform because the sum of the source phase and the receiving phase percentages add up to only 52%. Carrier 6, on the other hand, leaves 91% of the initial Cu(II) in the source phase, indicating a serious problem in its water-to-chloroform extraction capabilities.

As already indicated, one needs to know the time dependence of Cu(II) levels in all three phases in order to compare the carriers properly. Such data, rather rare in liquid membrane work, are presented in Figure 3 for LIX63 and the six ion carriers.

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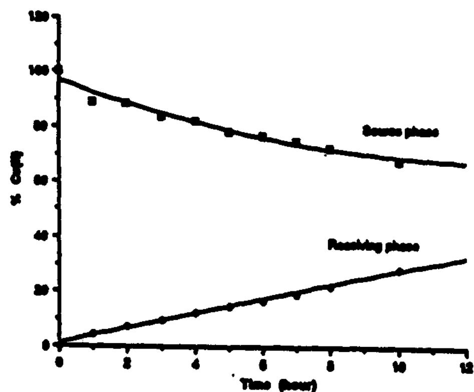
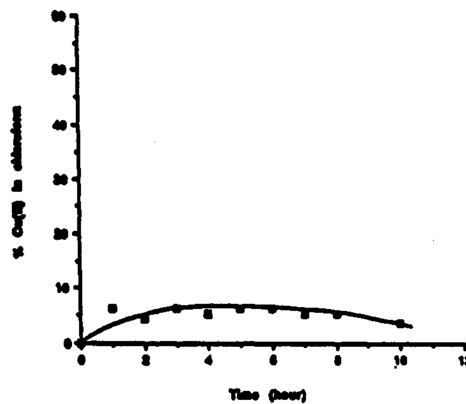
Carrier

LIX63





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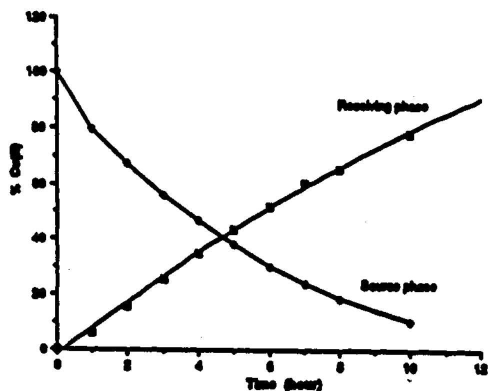

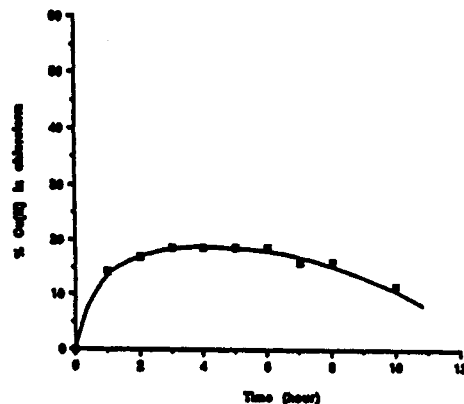

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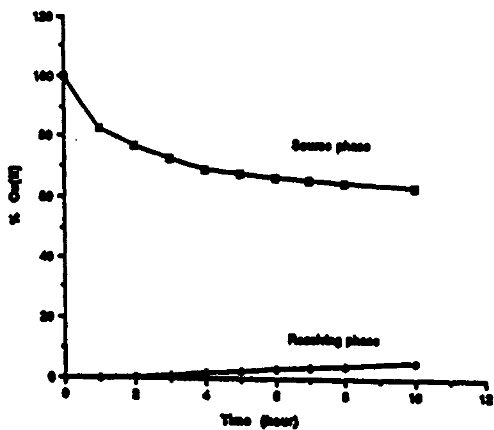

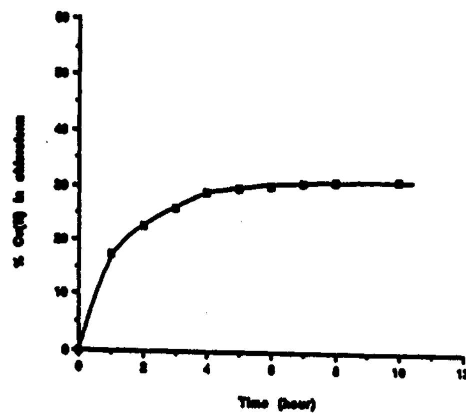

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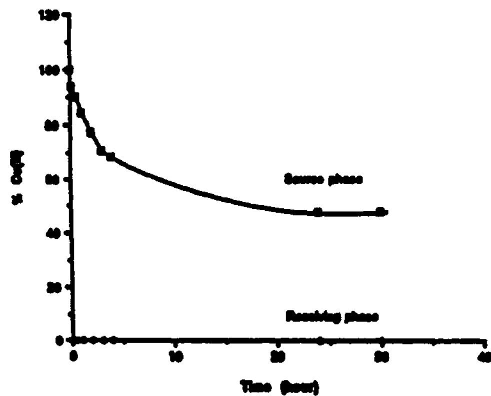

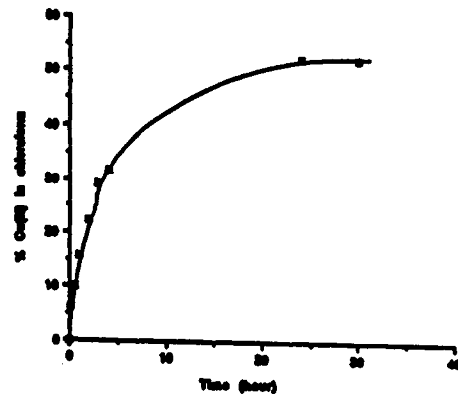

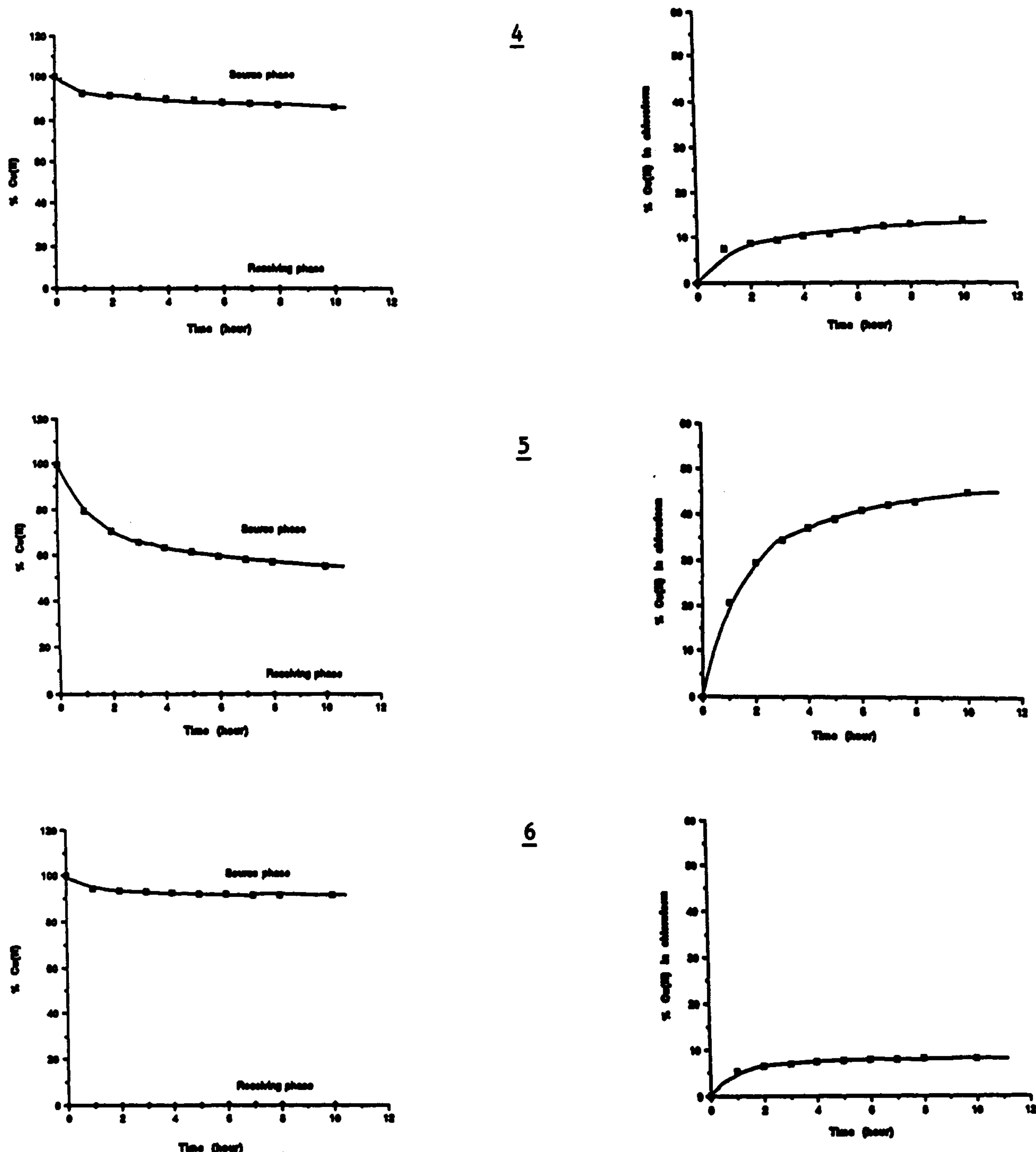

Figure 3. Percent of initial copper in the source phase and receiving phase (left column) and in the chloroform phase (right column) as a function of time (h) for carrier LIX63 and carriers 1–6 in Figure 2. Standard conditions described in text were used for all plots.

The question arose as to how effectively a carrier promotes Cu(II) extraction from the source phase into the chloroform in the *absence* of receiving phase. Thus, "chloroform uptake" experiments were carried out by vigorous shaking of the source phase (1.0 mL, 1.0 mM $CuSO_4$, pH = 4.63) with chloroform (1.0 mL, 1.0 mM carrier) for a few minutes until equilibrium was reached. The data are listed in Table II.

Along similar lines, we measured the "release efficiency" of the carrier complexes in the *absence* of a source phase. This was accomplished by shaking chloroform (1.0 mL, 1.0 mM carrier/metal complex) with receiving phase (1.0 mL, pH = 1.0). The results are also compiled in Table II.

In summary, we have (a) synthesized six new lipid carriers; (b) determined the Cu(II) content, as a function of time, of all three phases in the liquid membrane system; and (c) compared the relative partitioning equilibria of Cu(II) between chloroform and both the source and receiving phases in the presence of the carriers.

Discussion

No movement of Cu(II) through the chloroform was observed unless a carrier was used. Initially, Cu(II) in the source phase was, on a mole-to-mole basis, in a 2-fold excess over carrier in the chloroform. Since greater than 50% of the Cu(II) could be transferred to the receiving phase, a true "shuttling" mechanism must be operative. Transfer of >50% Cu(II) from the source to the receiving compartments also shows that an "uphill" transport is pos-

Table II. Uptake and Release of Copper(II)[a-c]

carrier	uptake of Cu(II), % pH = 4.63	release Cu(II), % pH = 1.0
1	92	96
2	61	86
3	98	0
4	51	81
5	95	21
6	12	88
LIX63	34	98

[a] Uptake: 1.0 mL of 1.0 mM carrier in chloroform shaken with 1.0 mL of 1.0 mM $CuSO_4$ in water (pH = 4.63). Release: 1.0 mL of 1.0 mM carrier–copper complex in chloroform shaken with 1.0 mL of water (pH = 1.0). See text for further details. [b] Numbers in table refer to percent of original copper extracted into the water phase. [c] Data represent average of two runs differing from one another by less than 5%.

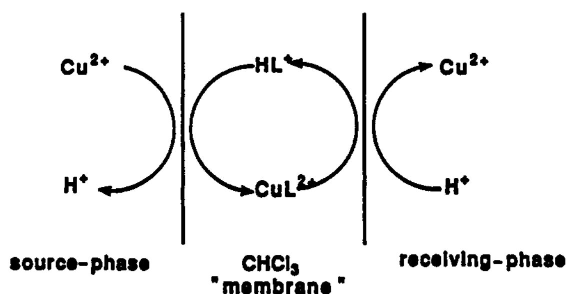

Figure 4. Reactions taking place at the boundary of the source phase and the chloroform and at the boundary of the chloroform and the receiving phase.

sible.[21] This can occur only via a counterflow of protons from the receiving phase to the source phase. Although not investigated quantitatively, the pH of the source-phase buffer was observed to drop by as much as 0.1 units after a prolonged run. Figure 4 represents, therefore, the ongoing chemistry.

Rate data in Table I and Figure 3 fail to correlate with partitioning data in Table II. This fact leads directly to a key insight: Transport in our liquid membrane system is controlled more by kinetic factors than by thermodynamics. Comparison of carrier **2** with LIX63, for example, proves this assertion. As seen in Table II, extraction of Cu(II) from source-phase into chloroform actually favors carrier **2** over LIX63 (i.e., 61% vs 32%, respectively). The two carriers differ little in their effect on Cu(II) partitioning between chloroform and receiving phase (86% and 98%, respectively). Yet, as is evident from Table I, LIX63 is a far better carrier in the liquid membrane system. Clearly, partitioning factors do not lie at the source of LIX63's effectiveness. One must conclude, by default, that LIX63 functions so well because it accelerates the rate of ion movement across the water–chloroform boundary.

Carrier **5** also illustrates the dominant role of rate over equilibrium. Table I data on carrier **5** show that after 10 h a full 55% of the original Cu(II) remains in the source phase. With the receiving-phase containing virtually no metal ion, the carrier in the chloroform must be 90% complexed. But Table II reveals that, under equilibrium conditions, carrier **5** releases 21% of its Cu(II) from the chloroform into the receiving-phase. These observations are best reconciled by a liquid membrane system where ion transfer into the receiving phase is at least partly rate-limiting.

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If partitioning equilibria were controlling ion transfer, then the contact area between water and chloroform should be irrelevant, which was not the case (as demonstrated by using glassware of different dimensions). It was for this reason that we were careful to use a single liquid membrane apparatus for the entire set of experiments. And it was for this reason that rate data are discussed here only in relative terms.

Kinetic control of the liquid membrane system could arise from (a) a slow ion movement across a water–chloroform interface or (b) a slow ion diffusion from one water compartment to the other through the chloroform. A simple control experiment supports the former explanation. Thus, when the stirring rate of the chloroform was varied by a factor of three (as determined stroboscopically), the effect on the transfer rate was minimal. We conclude that interfacial ion transport is rate limiting and that good carriers are those best able to promote the interfacial crossings.

Among the many ion transport catalysts we investigated, carrier **1** is by far the most effective. It is almost three times better than the commercial agent, LIX63. Comparison of carrier **1** with LIX63 (Table I, Figure 3) suggests that carrier **1** performs particularly well owing to its ability to remove Cu(II) from the source phase. For example, after 10 h only 10% of the Cu(II) remains in the source phase using carrier **1** (compared to 61% using LIX63). We surmise that the two polar hydroxyl groups of carrier **1** impart an affinity for the chloroform/water boundary. In other words, the amphiphilic character of carrier **1** promotes the interfacial adsorption step that must, obviously, precede actual metal complexation.

If the above rationale is correct, and Cu(II) extraction does indeed depend upon the population of interfacial carrier, then a good carrier must be neither too hydrophobic nor too hydrophilic. A proper balance of properties, such as found in surfactant-type molecules, seems necessary for optimum results. This conclusion is substantiated by ligands **7–10** that were found incapable of transporting Cu(II) into the receiving-phase after a 24-h operation of the liquid membrane system. Since the source phase became dark blue with these ligands, while the chloroform remained colorless, the metal/ligand complexes of **7–10** must be too water soluble to serve as good carriers.

Although carriers **2–6** are also ineffectual, they do display an ability to extract Cu(II) into the chloroform from the source phase. This is especially true of carriers **2**, **3**, and **5** that held 30–50% of the original Cu(II) in the chloroform after 10 h of stirring (Figure 3). Delivery of Cu(II) to the receiving phase constitutes, therefore, the main barrier to ion transport in these cases.

As already mentioned, carrier **1** is a remarkably potent transport agent for Cu(II) under our particular conditions. Carrier **1** excels even over the industry "standard", LIX63: 3.5×10^{-6} mol/h vs 1.2×10^{-6} mol/h. It was, therefore, interesting to probe more deeply into the parameters affecting the rate at which carrier **1** shuttles ions through the organic barrier.

No significant difference in transport rate was observed when the pH of the receiving phase was lowered from 1.0 to 0.7. On the other hand, elevating the pH from 1.0 to 2.0 had a pronounced adverse effect. As seen from Figure 5, the rate at pH = 2.0 is 10-fold slower than at pH = 1.0 (i.e., 0.35×10^{-6} mol/h vs 3.5×10^{-6} mol/h). Comparison of carrier **1** data at pH $\leq$ 1.0 (Figure 3) and pH = 2.0

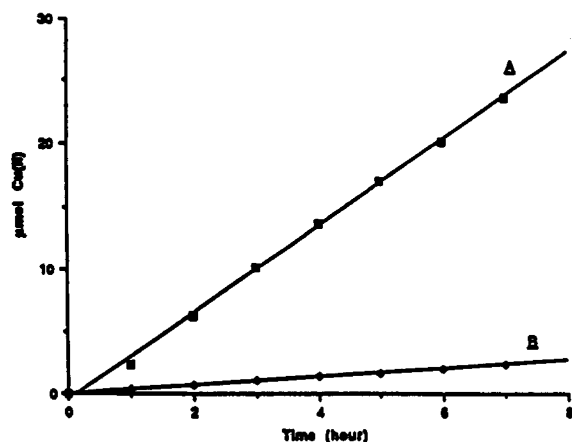

Figure 5. Cupric ion (μmol) transported by carrier 1, to the receiving phase as a function of time (h). Line A: a receiving phase of pH = 1.0. Line B: a receiving phase of pH = 2.0. All other conditions are those given in Table I and the text.

(Figure 6) helps explain the difference. Cu(II) complex reacts rapidly with the "pH = 1.0" receiving phase so that Cu(II) builds up to a maximum of only 18% in the chloroform layer. In contrast, the Cu(II) complex reacts slowly with the "pH = 2.0" receiving-phase with the result that Cu(II) accumulates to 38% in the chloroform. Once again it appears as if uptake of Cu(II) at the receiving phase limits the rate of transport.

Why should ion-transfer from a complex in chloroform to the aqueous receiving phase limit the rate? Two possible explanations come to mind. (a) Since the Cu(II) complex in the chloroform undoubtedly coordinates to the chloride counterions, the "headgroup" of the lipoidal complex is in fact not very polar. Its affinity for the chloroform/water interface may, as a consequence, be less than that of the metal-free ligand. This would, of course, favor the source-to-chloroform step over the chloroform-to-receiver step. (b) The exact mechanism of the metal/proton exchange at the chloroform/water boundary is not known. We presume that a proton competes with the metal for an unshared pair of electrons on the ligand. Protonation of one nitrogen should help the protonation of another, and in this manner the metal complex "unzips". Thus, not only must the complex reach the chloroform/water interface, the complex must encounter an acidity sufficient to protonate a metal-coordinated amine. We speculate, on the basis of the rate identity between pH = 0.7 and pH = 1.0, and on the basis of the slow rate at pH = 2.0, that pH = 1.0 approximates the pH where adsorption to the interface becomes totally rate limiting.

Plots of μmol of Cu(II) in the receiving phase vs time (not shown) were linear for the first half-life at three different carrier 1 concentrations, a fact also true for LIX63. Saturation phenomena might manifest themselves at higher carrier concentrations, but this point was not investigated.

Finally, we should point out that transport rates in liquid membranes are not indifferent to the nature of the organic solvent. Thus, carrier 1 transport rates of 3.5×10^{-6} mol/h, 1.9×10^{-6} mol/h, and 0.35×10^{-6} mol/h were determined in chloroform, methylene chloride, and carbon tetrachloride, respectively. Carbon tetrachloride is also a poor solvent for LIX63 transport.

In summary, it is clear that liquid membrane chemistry is a complex business involving the interplay of many factors most of which are never quantified. These include carrier and complex solubilities in water and organic solvents, interfacial affinities of carrier and its complex, the pH differential driving the transport, ion-carrier association strength,[22] the pK_a of the carrier, and the nature of the organic solvent. We examined a few of these parameters, but the field is, of course, far from the stage where predicting transport activity is possible. As stated by Izatt et al.,[23] "Perhaps the greatest need in the design of carrier-mediated liquid systems is that of obtaining proper carrier molecules". Our most important specification in this regard is the desirability that the carrier possess amphiphilic character (i.e., organic solubility but with a ligand polarity to impart an interfacial affinity). The remarkable effectiveness of carrier 1 bears this out. Certainly our work underscores the need to investigate the ion content of all three phases if there is any desire to understand the significance of liquid membrane transport rates.

Experimental Section

Liquid Membrane. Certain details of the liquid membrane system (Figure 1) were described in previous sections. The cylindrical membrane cell was 3.5 cm in diameter and 11.5 cm in height. It was divided into two equal compartments by a glass partition that ran vertically from the opening to within 1 cm of the flat bottom plate. Since absolute transport rates depend on cell geometry, a single apparatus was used throughout. The cell was filled with the three phases, as already described, and sealed with a rubber septum to minimize evaporation. Stirring of the chloroform was carried out magnetically using a 0.5-in. bar placed in the center of the bottom plate.

Copper Analysis.[24] Cu(II) in the source phase and receiving phase was determined colorimetrically using a stock solution of diethyldithiocarbamic acid (sodium salt trihydrate, 20 g) dissolved in 500 mL of methanol. Stock solution (3.0 mL) was placed in a 1-cm cuvette and mixed with a 50-μL aliquot from the source or receiving phase. The absorbance at 433 nm of the resulting brown solution was then determined with the aid of a Shimadzu UV-120-02 spectrophotometer. Absorbance data were converted into concentration using a linear standard curve prepared from known Cu(II) concentrations (e.g., an absorbance of 1.0 corresponds to 4.4 mM cupric ion).

Materials. LIX63 (40–50% in kerosene) was obtained from Tokyo Kasei and was used after removing the solvent under reduced pressure for several days. The following were purchased from Aldrich and used as received after spectroscopic validation of their identity: 7, 8, 9, and diethyldithiocarbamic acid. Lancaster provided ligand 10. Solvents were ACS-certified quality. The syntheses of carriers 1–6, which have to our knowledge not been described before in the literature, are presented below. "Recipe" format is employed to avoid passive voice. Full analytical data are presented elsewhere.[25]

Carrier 1. Suspend ethylenediaminetetraacetic acid (26 g) in pyridine (100 g) and acetic anhydride (100 g). Stir at 70 °C for 36 h, filter the product, wash it with 500 mL of acetic anhydride and 300 mL of dry ether, and dry under reduced pressure to give ethylenediaminetetraacetic dianhydride[26] (15 g, 59%), mp 194–195 °C, with a correct IR and elemental analysis (EA). Reflux the dianhydride (9.0 g, 35 mmol) and hexadecylamine (17 g, 70

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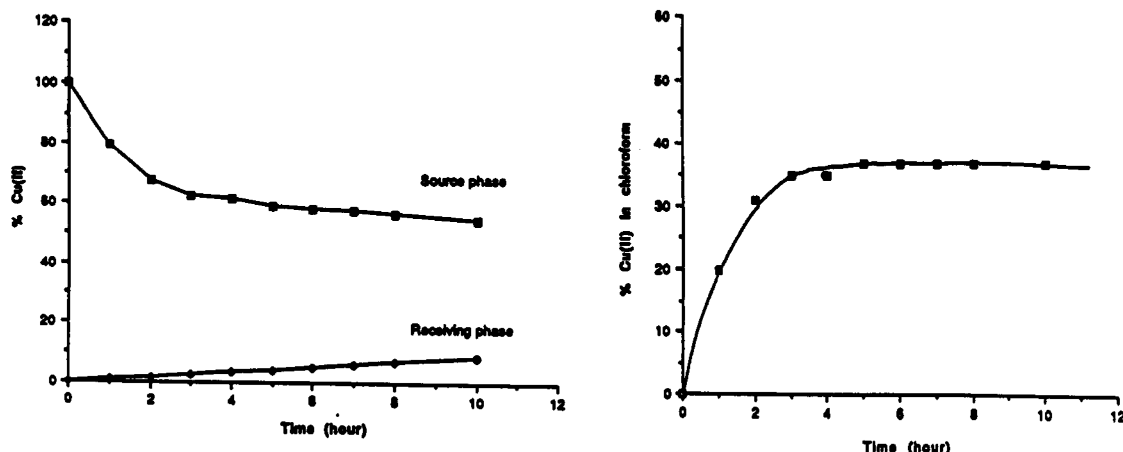

Figure 6. Percent of initial copper in the source phase and receiving phase (left) and in the chloroform phase (right) as a function of time (h) for carrier 1 when the receiving phase has a pH of 2.0. See Figure 3 for corresponding plots when the receiving phase has a pH of 1.0.

mmol) in THF (200 mL) for 24 h, remove solvent, and crystallize from toluene to give 21.5 g (81%) of *N,N'*-bis(carboxymethyl)-*N,N'*-bis[(*N*-hexadecylcarbamoyl)methyl]ethylenediamine, mp 155–160 °C, whose structure was proven by NMR, IR, MS, and EA. To prepare *N,N'*-bis(hydroxyethyl)-*N,N'*-bis[2-(hexadecylamino)ethyl]ethylenediamine (carrier 1), mix precursor (5 g, 6.7 mmol) and $LiAlH_4$ (6 g) in anhydrous ether (200 mL) reflux for 24 h. Dilute with ether, quench with water, and wash with 1 N HCl, water, 1 N NaOH, and water in that order. Dry organic phase over Na_2SO_4 and remove solvent under vacuum to obtain a pale yellow solid (3.5 g, 76%, mp 47–48 °C) whose structure as carrier 1 was confirmed by NMR, IR, MS, and EA.

Carrier 2. Reflux a mixture of benzyl glycerol[27] (4.1 g, 22.5 mmol), 1-bromohexadecane (30.0 g, 98 mmol), KOH (6.0 g), and 50 mL of benzene for 20 h while removing water with the aid of a Dean-Stark receiver. Cool, dilute with ether, and wash successively with water (2 × 100 mL). Dry the ether/benzene solution over Na_2SO_4 and remove solvent plus unreacted hexadecyl bromide under vaccum (ultimately reaching 140 °C/1 mmHg). The residual oil (7.0 g, 52%, correct NMR and IR for α,β-di-*O*-hexadecyl-2'-*O*-benzylglycerol)[28] was used without purification. Stir a mixture of this glycerol derivative (5.0 g, 7.9 mmol), 1.0 g of Pd/C, and 300 mL of ethyl acetate under a H_2 atmosphere overnight. Remove catalyst by filtration, wash it with $CHCl_3$, and strip the combined filtrate and wash to give an oil that was crystallized in $CHCl_3$–MeOH (250 mL, 91:4 v/v) at 0 °C to give 2.1 g (49%) of α,β-di-*O*-hexadecylglycerol,[28] mp 55–56 °C, with the expected NMR, IR, MS, and EA. Mix this diether (2.2 g, 4 mmol) with 100 mL of ether, 100 mL of pyridine, and *p*-toluenesulfonyl chloride (2.4 g, 12.5 mmol) at 0 °C for 3 h and then at room temperature overnight. Dilute with ether (200 mL), wash with 0.1 N HCl (100 mL, 3×) and water (100 mL, 3×), dry the ether over Na_2SO_4, and remove the solvent to give a solid residue that was crystallized from 1-butanol/methanol (4:1) to yield 2.1 g (76%) of white solid, mp 47–49 °C, with the correct NMR, IR, and MS for α,β-di-*O*-hexadecyl-α^1-*O*-tosyl glycerol which was used immediately without purification for the final step: Reflux the preceding glycerol derivative (2.2 g, 3 mmol), K_2CO_3 (5 g), *N,N,N'*-trimethylethylenediamine (3 g), and THF (80 mL) for 4 days. Cool, dilute with 300 mL of ether, wash with aqueous K_2CO_3 and water, dry the ether, and remove it under reduced pressure to give a residue (1.5 g) that is dissolved in hot heptane and then cooled to −5 °C. Remove the resulting precipitate by filtration, discard it, and strip the filtrate to give 1.0 g (53%) of almost colorless oil identified by NMR, IR, MS, and EA to be carrier 2: 1-*N,N,N'*-trimethyl-*N'*-[2,3-bis(hexadecoxy)propyl]ethylenediamine.

Carrier 3. Stir the following mixture at 50 °C for 2 days: octadecylamine (4.0 g, 15 mmol), 2-picolyl chloride hydrochloride (5.0 g, 30 mmol), NaOH (2.5 g, 63 mmol in 100 mL of water), and THF (100 mL). Cool, collect the brown organic phase that separates, remove the solvent under reduced pressure, and chromatograph the residual oil (silica gel eluted with 1:1 methanol/ethyl acetate) to give *N,N*-bis(2-pyridylmethyl)octadecylamine (carrier 3) as a light brown solid (5.2 g, 75%, mp 45–45.5 °C) having the expected NMR, IR, MS, and EA.

Carrier 4. Mix under a blanket of N_2 at −78 °C 2,9-dimethyl-1,10-phenanthroline (2 g, 9.6 mmol) in THF (150 mL) and LDA in cyclohexane (1.5 M, 15 mL). Wait 1 h and add 1-iodoundecane (6 g, 21 mmol) in 30 mL of dry THF. Stir for 5 h at −78° C, allow to warm to room temperature overnight, remove solvent under reduced pressure, add 200 mL of benzene to the residual oil, wash benzene solution with water (3 × 50 mL), dry over Na_2SO_2, remove solvent, and crystallize the solid residue from ethyl acetate to give 4.0 g (80%) of a white solid (mp 76–77 °C) identified from NMR, IR, MS, and EA to be 2,9-didodecyl-1,10-phenanthroline (carrier 4).

Carrier 5. Add 4,7-dimethyl-1,10-phenanthroline (1 g, 4.8 mmol) in 150 mL of THF to LDA in cyclohexane (1.5 M, 8 mL) under N_2 at −78 °C. After 1 h add 1-iodoundecane (3 g, 10.5 mmol) in 30 mL of dry THF and stir for 5 h at −78 °C and overnight at room temperature. Remove solvent, dilute residue with 100 mL of benzene and wash with water (3 × 25 mL), dry the organic phase over Na_2SO_4, remove the organic solvent, and crystallize the solid residue from ethyl acetate to produce 800 mg of tan solid. Crystallize once more from acetonitrile to give 600 mg (25%) of white needles of 4,7-didodecyl-1,10-phenanthroline (carrier 5) with a mp of 68–69 °C and correct NMR, IR, MS, and EA.

Carrier 6. Stir overnight at room temperature a mixture of 1,4,10,13-tetrathia-7,16-diazacyclooctadecane (0.50 g, 1.5 mmol), triethylamine (1.8 g), and stearoyl chloride (1.2 g, 4.0 mmol) in 200 mL of CH_2Cl_2. Wash reaction mixture with 0.1 N HCl (3 × 100 mL) and water (3 × 100 mL) and dry over Na_2SO_4, and remove solvent under reduced pressure. Purify the resulting white solid by column chromatography (silica gel, ethyl acetate eluent) to obtain 1.1 g (85%) of product, mp 90–92 °C, having spectroscopic (NMR, IR, MS) and analytical (EA) data consistent with 7,16-distearoyl-1,4,10,13-tetrathia-7,16-diazacyclooctadecane. To obtain carrier 6, reduce this diamide (1.1 g, 1.3 mmol) in 100 mL of THF with 100 mL of 1 M $LiAlH_4$ in THF via an overnight reflux. Remove solvent at room temperature, dissolve resulting solid in 500 mL of benzene, wash with 0.1 N NaOH (3 × 100 mL) and water (3 × 100 mL) dry over Na_2SO_4, remove the solvent, and purify the solid residue chromatographically (silica gel, 1:1 ethyl acetate/$CHCl_3$ eluent) to obtain 0.91 g (88%) of white solid, mp 72–73 °C. NMR, IR, MS, and EA data demonstrate the product to be carrier 6 with the chemical name of 7,16-distearyl-1,4,10,13-tetrathia-7,16-diazacyclooctadecane.

Additional Note. Since many of the above workups utilized benzene, work was always carried out in a well-drawing hood. It is recommended for environmental and safety reasons, however, that anyone repeating the syntheses use an alternative solvent.

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Copper Complexes. Cu(II) complexes were prepared for carriers **1–6**. This was accomplished by adding slowly a solution of carrier in absolute enthanol to a 1.7-fold molar excess of $CuCl_2$ in absolute ethanol. Solvent was removed and the residue chromatographed or crystallized to give products characterized by elemental analysis (C, H, Cl, and N). Complexes of **1**, **2**, and **3** are blue, whereas complexes of **4** and **5** are brown. Carrier **6** formed a brown binuclear complex[29] with $CuBr_2$. Details are given elsewhere.[25]

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Supplementary Material Available: Analytical data (NMR, IR, MS, and elemental analyses) for the six new ligands (**1–6**) (6 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information. Please note that X-ray structures of the copper complexes of **4** and **5**, as well as the C_{14} analog of **3**, are given in: Menger, F. M.; Lee, J.-J.; Hagen, K. S. *J. Am. Chem. Soc.* **1991**, *113*, 4017.