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ELECTRON TRANSPORT ACROSS ARTIFICIAL LIPOSOMAL MEMBRANES AIDED BY PHASE-TRANSFER OF THE MOVABLE ELECTRON CARRIER. CORRELATIONSHIP BETWEEN HYDROPHOBICITY AND CARRIER EFFICIENCY.

Iwao Tabushi* and Shin-ichi Kugimiya
Department of Synthetic Chemistry
Kyoto University, Sakyo-ku, Kyoto, 606 Japan

Electron transport across single wall, bimolecular lecithin liposomal membranes from exterior $S_2O_4^{=}$ to interior ferricyanide or FMN (riboflavin 5'-phosphate) were investigated. A series of alkylviologens were used as electron carriers. The *overall* electron trasport rates increased with the carbon number of the alkyl chain for C_1 - C_4, then decreased monotonically until C_{18}. Measurement of the distribution of the viologens, and the corresponding viologen cation radicals, between H_2O/CH_2Cl_2 or H_2O/lecithin liposome were carried out independently. These results, together with the rate measurements, clearly demonstrate that the overall electron transport rates are primarily controlled by the phase-transfer of the alkylviologen cation radicals from the exterior aqueous phase to the membrane for C_1 - C_4, and by the phase-transfer of the cation radicals from the membrane to the interior aqueous phase for C_4 - C_{18}. This leads to optimal electron transport for the C_4 viologen.

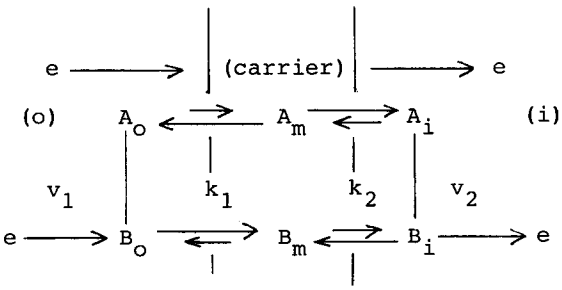
It is well known that the oxidation-reduction potential gradient, applied across the membrane in a water-membrane-water three phase system, has the potential to drive the "vectorial" electron transport (one-directional electron flow)[1]. However, the "apparent permeability" of the "typical" membrane to an "electron" is low and, as a result, the observed *overall* electron transport rates are not simply determined by the oxidation-reduction potential gradient. Instead, they are highly sensitive to the electron transporting (electron acceptance and/or release) ability of a mediating electron carrier. When the electron carrier is tightly bound to the membrane, the electron transport rate is controlled by the rates of "overall" electron uptake and release from the bound carrier (Type I electron transport, or electron channel mechanism). Both the uptake and release rates are strictly determined by the surface area of the interphase[2].

Now the authors wish to report another type of electron transport, Type II, or movable electron carrier mechanism, in which an electron carrier distributed in both phases is phase-transferred from one phase to the other on electron acceptance. In the observed Type II electron transport, single wall, bimolecular egg-lecithin liposomes functionalized with alkylviologens were used. Phase-transfer of the viologens from the aqueous phase to the membrane was induced by a decrease in the number of charges on the viologens during electron acceptance[3] (see Scheme 1).

Type II electron transport is especially effective for systems in which the overall electron uptake is well balanced with the overall electron release ($k_1 \approx k_2$).

Thus, artificial liposomes containing $K_3Fe(CN)_6$ or FMN (flavin mononulestide) in their interior solutions were prepared according to the reported procedures[4]. The liposomes, after necessary purification, were equilibrated with a certain alkylviologen in an aqueous solution and the equilibrium of the viologen in the water-liposome system was measured by electronic spectroscopy[5] and chromatography[6]. The results are summarized in Table 1. Then the liposome solution, modified with the viologen (V^{++}), ($V^{++(o)}|\ Lip{\cdot}V^{++}|^{(i)}\ V^{++}\ K_3Fe(CN)_6$) or ($V^{++(o)}|Lip{\cdot}V^{++}|^{(i)}V^{++}$,FMN), was mixed with an aqueous $Na_2S_2O_4$ solution in a specially designed stopped flow appratus[1h], and the decrease of the $Fe(CN)_6^{3-}$ or increase in the FMNH concentration was followed by electronic spectroscopy. The observed "overall" electron transport rates increased until the maximum value at C_4 was reached, then the rates decreased monotonically, with an increase in the hydrophobicity of the viologens (see Fig 1).

Scheme 1. Electron transport mechanism



A: C_4V^{++}, B: $C_4V^{+\cdot}$ (viologen cation radical); A_o, 8×10^{-5}; A_m, 2×10^{-6}; A_i, 8×10^{-5}; B_o, 5×10^{-6}; B_m, 1.5×10^{-5}; B_i, 5×10^{-6} (see also Fig 1, Table 2)

Table 1. Equilibrium constants, $K_{eq} = [C_nV]_{org}/[C_nV]_{aq}$

$C_nV^{+\cdot}$, n (carbon number)	1	2	3	4	5	6	8
CH_2Cl_2, K_{eq}	0.25		2.0	4.6	10	50	200
Lip, K_{eq}/ 100		0.67		6.8		640	

C_nV^{++}, n =	3	6	8	10	12	14
CH_2Cl_2, K_{eq} x 100		0.01	0.04	1.0	11	33
Lip, K_{eq}/ 100	0.04	0.5	2.0	6.0	30	100

Independently measured were the rates of electron acceptance and release of typical viologens (v_1 and v_2 for n = 1,4 and 8) in aqueous solutions (see Table 2), and the equilibrium constants in the present series of viologen radical cations (n = 1,2,3,4,5,6 and 8) between two phases (K_1 or K_2 ; for CH_2Cl_2/H_2O and lecithin-liposome/H_2O, see Table 1). The equilibrium measurements clearly indicate that moderately hydrophobic viologens (hexyl-decyl) are efficiently phase-transferred on one electron acceptance (see Table 1). Interestingly, this "phase-transfer region" is remarkably shifted to shorter chains (C_2- C_6) in the binding by lecithin-liposome (see Table 1). These results combined with kinetic measurements indicate that with increasing hydrophobicity the observed initial increase in the overall rates

Figure 1. Electron flux across the membrane mediated by alkylviologens,

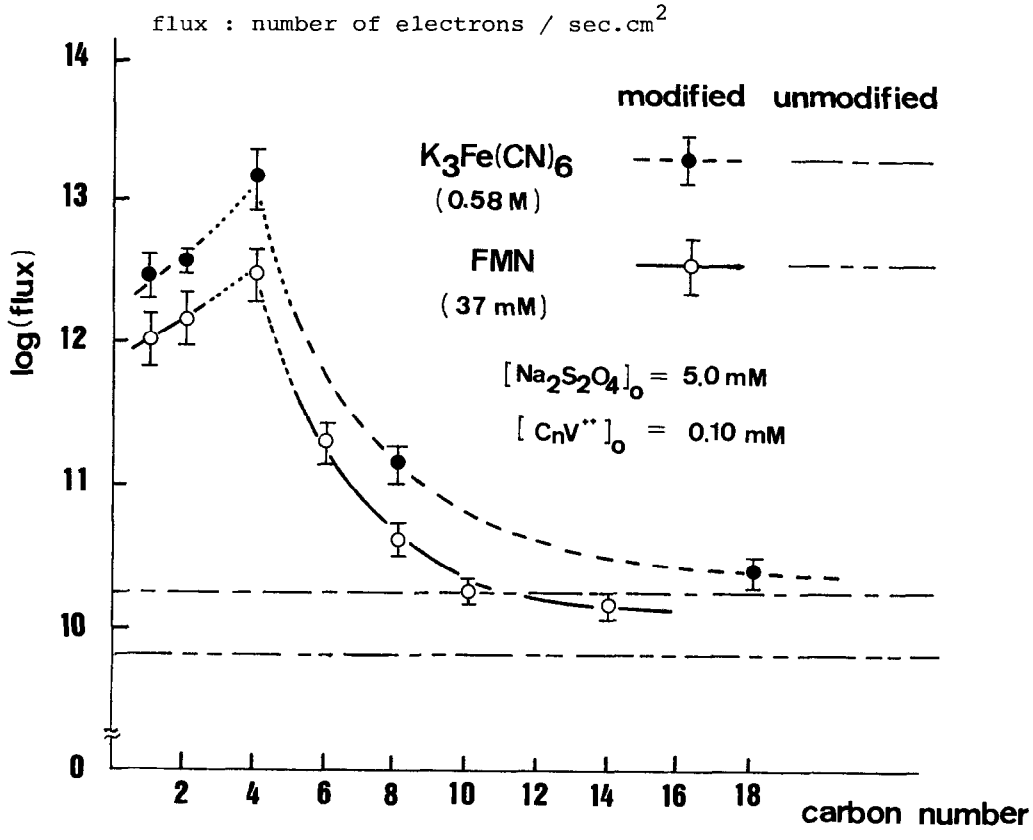


Table 2. Rates of electron acceptance and release for alkylviologens

v_1(relative), $Na_2S_2O_4$	C_1	3.6				C_8	1.0
v_2(M^{-1},s^{-1}), FMN	C_1	5.9×10^4	C_4	0.9×10^4		C_8	6.9×10^3

(C_1 - C_4) is mainly due to the enhancement in the phase-transfer (water to membrane) of the viologen cation radical, at the outer surface on electron acceptance. While the observed decrease in the rates (C_4 - C_{18}) is mainly due to the less favorable phase-transfer of the cation radical from the membrane to the interior aqueous phase. Obviously, the two different mechanisms "coalesce" at C_4 (see Fig 1), where both phase-transfers are well balanced, and therefore, provide the maximum electron flow. Since the homogeneous oxidation-reduction rates (v_1 and v_2) were rather insensitive to the length of the alkyl chain, the structure-dependent reactivity change did not markedly affect the overall electron flow. Therefore, the observed structure dependence of the rates is mainly determined by the phase-transfer. The rates of phase-transfers in the micellar systems reported were within a range of 10^7 - $10^9 M^{-1}s^{-1}$ for association and 10^3 - $10^9 s^{-1}$ for dissociation[8].

Based on these data, a mechanism is proposed, whereby influx and efflux of the viologen cation radical mainly determine the overall electron flow (see Scheme 1). Detailed kinetic analysis of ten competitive and consecutive steps involved in the present system is now under way.

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