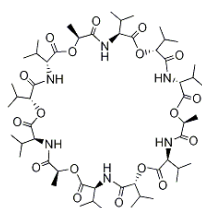


Potassium

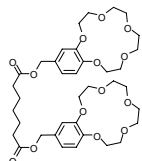


Potassium ionophore I

(Valinomycin)

$C_{54}H_{90}N_6O_{18}$ $M_r = 1111.13$ [2001-95-8]

[60403](#) **Selectophore®**, function tested 10 mg, 100 mg

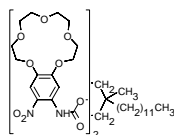


Potassium ionophore II

(Bis[(benzo-15-crown-4)-4'-ylmethyl]pimelate)

$C_{37}H_{52}O_{14}$ $M_r = 720.82$ [69271-98-3]

[60401](#) **Selectophore®**, function tested 25 mg, 100 mg, 1g

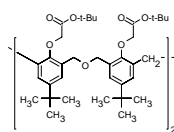


Potassium ionophore III

(BME 77; [2-Dodecyl-2-methyl-1,3-propanediyl-bis-[N-(5'-nitro(benzo-15-crown-5)-4'-yl)carbamate])

$C_{46}H_{70}N_4O_{18}$ $M_r = 967.09$ [99348-39-7]

[60397](#) **Selectophore®**, function tested 25 mg, 100 mg



Potassium ionophore IV

(4-*tert*-Butyl-2,2,14,14-tetrahydro-2a,14a,dioxacalix[4]arene-tetraacetic acid tetra-*tert*-butyl ester)

$C_{77}H_{100}O_{14}$ $M_r = 1165.53$ [135463-06-8]

[60396](#) **Selectophore®**, function tested 10 mg, 50 mg

Potassium ionophore I – Cocktail A

Potassium-selective membrane solution for microelectrodes (high impedance)

[60031](#) **Selectophore®** solution in 0.5 ml tetrahydrofuran

Potassium ionophore I – Cocktail B

Potassium-selective membrane solution for microelectrodes (low impedance)

[60398](#) **Selectophore®** package with 0.1 ml

Electrochemical Transduction

- Ion-Selective Electrodes
- Microelectrodes
- Ion-selective Field Effect Transistors
- Ion-selective Conductometric Microsensors
- Chemically Modified Electrodes
- Optical Transduction

Electrochemical Transduction

Ion-Selective Electrodes

Application 1 and Sensor Type ^{1,2,3,4,5}

Assay of K⁺ activity in diluted urine, whole blood, plasma, serum and aqueous solutions with solvent polymeric membrane electrodes based on Potassium ionophore I.

Recommended Cell Assembly

Reference || sample solution || liquid membrane | 0.004 M KCl | AgCl,Ag

Recommended Membrane Composition

1.00	wt%	Potassium ionophore I (60403)
65.50	wt%	Bis(1-butylpentyl) decane-1,10-diyl diglutarate (ETH 469) (30585)*
0.50	wt%	Potassium tetrakis(4-chlorophenyl)borate (60591)
33.00	wt%	Poly(vinyl chloride) high molecular weight (81392)

* The use of [bis\(1-butylpentyl\) adipate \(BBPA\)](#) or [bis\(2-ethylhexyl\)sebacate \(DOS\)](#) leads to membrane electrodes of similar performance.

Electrode Characteristics and Function

Selectivity Coefficients	$\log K_{K, M}^{\text{Pot}}$	required ¹⁾	found ²⁾
$\log K_{K, H}^{\text{Pot}}$		< 2.8	-3.4
$\log K_{K, Na}^{\text{Pot}}$		< -3.6	-4.1
$\log K_{K, Mg}^{\text{Pot}}$		< -2.8	-5.7
$\log K_{K, Ca}^{\text{Pot}}$		< -2.9	-5.2
Stability:	Drift [mV h ⁻¹]:		0.01
	Standard deviation [mV]	< 0.46	0.03
	Reproducibility [mV]		0.16
Lifetime:	$\log P_{\text{TLC}}^{\text{3)}$ ionophore > 8.4	8.6	
	$\log P_{\text{TLC}}^{\text{3)}$ plasticizer > 12.8	10.8	

¹⁾ for measurements in blood (1% interference, worst case) ^{6,7}

²⁾ membrane without potassium tetrakis(4-chlorophenyl)borate

³⁾ lipophilicity, determined by thin layer chromatography ⁸

¹ D. Ammann, P. Anker, E. Metzger, U. Oesch, W. Simon, in: Ion Measurements in Physiology and Medicine, Eds. M. Kessler, D.K. Harrison, J. Höper, Springer-Verlag, Berlin, Heidelberg 120 (1985)

² D.M. Band, J. Kratochvil, P.A. Poole Wilson, T. Treasure, Relationship between activity and concentration measurements of plasma potassium, **Analyst** **103**, 246 (1978).

³ J.L. Hill, L.S. Gettes, M.R. Lynch, N.C. Hebert, Flexible valinomycin electrodes for on-line determination of intravascular and myocardial K⁺, **Am. J. Physiol.** **235**, H455 (1978).

⁴ H.-B. Jenny, C. Riess, D. Ammann, B. Magyar, R. Asper, W. Simon, HDetermination of K⁺ in diluted and undiluted urine with ion-selective electrodesH, **Mikrochim. Acta** **74**, 309. (1980).

⁵ H.F. Osswald, R. Asper, W. Dimai, W. Simon, On-line continuous potentiometric measurement of potassium concentration in whole blood during open-heart surgery, **Clin. Chem.** **25**, 39 (1979).

⁶ A. Lewenstam, Ion selective electrodes in clinical chemistry, **Anal. Proc.** **28**, 106 (1991)

⁷ U. Oesch, P. Anker, D. Ammann, W. Simon, in: Ion-Selective Electrodes, ed. E. Pungor, I. Buzás, Akadémiai Kiadó, Budapest (1985).

⁸ O. Dinten, U.E. Spichiger, N. Chaniotakis, P. Gehrig, B. Rusterholz, W.E. Morf, W. Simon, Lifetime of neutral-carrier-based liquid membranes in aqueous samples and blood and the lipophilicity of membrane components, **Anal. Chem.** **63**, 596 (1991).

Application 2 and Sensor Type ^{4,9,10}

Assay of K⁺ activity in undiluted urine, whole blood, plasma, serum, and aqueous solutions with solvent polymeric membrane electrodes based on Potassium ionophore I.

Recommended Cell Assembly

Reference || sample solution || liquid membrane | 0.1 M KCl | AgCl,Ag

Recommended Membrane Composition

2.50	wt%	Potassium ionophore I (60403)
83.00	wt%	Siloprene K 1000 (85417)
14.50	wt%	Siloprene Crosslinking Agent K11 (85418)

Electrode Characteristics and Function

Selectivity Coefficients $\log K_{K,M}^{\text{Pot}}$ as obtained by the separate solution method.

	required ¹⁾	found
$\log K_{K,H}^{\text{Pot}}$	<2.8	-4.4
$\log K_{K,Li}^{\text{Pot}}$	<-1.7 ²⁾	-4.3
$\log K_{K,Na}^{\text{Pot}}$	<-3.6	-4.0
$\log K_{K,Mg}^{\text{Pot}}$	<-2.8	-4.3
$\log K_{K,Ca}^{\text{Pot}}$	<-2.9	-4.2

Lifetime: $\log P_{\text{TLC}}^{\text{Pot}}$ ionophore >8.4 8.6

¹⁾ for measurements in blood (1% interference, worst case) ^{6,7}

²⁾ therapeutical Li⁺ concentrations

³⁾ lipophilicity, determined by thin layer chromatography ⁸

Application 3 and Sensor Type ^{11,12,13,14}

Assay of K⁺ activity for cardiovascular application with biocompatible solvent polymeric membrane electrodes and related microfabricated sensor arrays based on Potassium ionophore I.

Recommended Membrane Composition

1.00	wt%	Potassium ionophore I (60403)
0.50	wt%	Potassium tetrakis(4-chlorophenyl)borate (60591)
49.50	wt	Bis(2-ethylhexyl)sebacate (84818)
49.00	wt%	Poly(vinyl chloride) carboxylated (1.8% carboxyl content) (81395)

⁹ P. Anker, H.-B. Jenny, U. Wuthier, R. Asper, D. Ammann, W. Simon, Determination of [K⁺] in blood serum with a valinomycin-based silicone rubber membrane of universal applicability to body fluids, **Clin. Chem.** **29**, 1447 (1983).

¹⁰ D. Ammann, P. Anker, H.-B. Jenny, W. Simon, in: Ion-Selective Electrodes, Eds. E. Pungor, I. Buzás, Akadémiai Kiadó, Budapest (1981).

¹¹ V.V. Cosofret, M. Erdösy, E. Lindner, T.A. Johnson, R.P. Buck, W.J. Kao, M.R. Neuman, J.M. Anderson, Ion-selective microchemical sensors with reduced preconditioning time: Membrane biostability studies and applications in blood analysis, **Anal. Lett.** **27**, 3039 (1994).

¹² V.V. Cosofret, M. Erdösy, T.A. Johnson, R.P. Buck, R.B. Ash, M.R. Neuman, Microfabricated sensor arrays sensitive to pH and K⁺ for ionic distribution Measurements in the Beating Heart, **Anal. Chem.** **67**, 1647 (1995).

¹³ V.V. Cosofret, M. Erdösy, R.P. Buck, W.J. Kao, J.M. Anderson, E. Lindner, M.R. Neuman, Electroanalytical and biocompatibility studies on carboxylated poly(vinyl chloride) membranes for microfabricated array sensors, **Analyst** **119**, 2283 (1994).

¹⁴ V.V. Cosofret, M. Erdösy, T.A. Johnson, B.A. Bellinger, R.P. Buck, R.B. Ash, M.R. Neuman, Electroanalytical and Surface Characterization of Encapsulated Implantable Membrane Planar Microsensors, **Anal. Chim. Acta** **314**, 1 (1995).

Electrode Characteristics and Function

Selectivity Coefficients $\log K_{K, M}^{\text{Pot}}$ as obtained by the separate solution method (0.1 M solutions of chlorides).

$\log K_{K, \text{Li}}^{\text{Pot}}$	-3.98	$\log K_{K, \text{Ca}}^{\text{Pot}}$	-4.30
$\log K_{K, \text{Na}}^{\text{Pot}}$	-3.56	$\log K_{K, \text{NH}_4}^{\text{Pot}}$	-1.81

Slope of linear regression: 57.5 ± 0.2 mV (10^{-5} to 10^{-1} M KCl)
 Detection limit (KCl, ion background of 140 mM Na⁺): $4 \cdot 10^{-6}$ M K⁺
 Membrane resistance (10^{-2} M KCl at pH 7.0 with TRIS buffer): 3.17MΩ

Application 4 and Sensor Type ^{15, 16}

Assay of K⁺ activity with double-matrix membrane ion-selective electrodes based on Potassium ionophore I

Recommended Membrane Composition

2.00	wt%	Potassium ionophore I (60403)
0.50	wt%	Potassium tetrakis(4-chlorophenyl)borate (60591)
64.70	wt%	Bis(2-ethylhexyl)sebacate (84818)
32.80	wt%	Poly(vinyl chloride) high molecular weight (81392)

Recommended Cell Assembly

Ag, AgCl | 3 M KCl | | 0.3 M NH₄NO₃ | | sample solution | | liquid membrane | 0.1 M NaCl | AgCl, Ag

Electrode Characteristics and Function

Selectivity Coefficients $\log K_{K, M}^{\text{Pot}}$ as obtained by the separate solution method (0.1 M solutions of the chlorides).

$\log K_{K, \text{Na}}^{\text{Pot}}$	-4.2
$\log K_{K, \text{Li}}^{\text{Pot}}$	-4.3

Slope of linear regression: 58 mV ($1.8 \cdot 10^{-5}$ to 10^{-1} M K⁺)
 Detection limit: $3 \cdot 10^{-6}$ M K⁺
 Lifetime: >1 month

¹⁵ M. Knoll, K. Cammann, C. Dumschat, M. Borchardt, G. Högg, Microfibre matrix-supported ion-selective PVC membranes, **Sens. Actuators B20**, 1 (1994).

¹⁶ M. Borchardt, C. Dumschat, K. Cammann, M. Knoll, Disposable ion-selective electrodes, **Sens. Actuators B24-25**, 721 (1995).

Application 5 and Sensor Type ^{17,18}

 Assay of K⁺ activity with solvent polymeric membrane electrodes based on Potassium ionophore II.

Recommended Membrane Composition

2.80	wt%	Potassium ionophore II (60401)
69.40	wt%	Dibutyl phthalate (80100)
27.80	wt%	Poly(vinyl chloride) high molecular weight (81392)

Recommended Cell Assembly

Reference | | sample solution | | ion-selective membrane | 0.001 M KCl | AgCl, Ag

Electrode Characteristics and Function

 Selectivity Coefficients $\log K_{K, M}^{\text{Pot}}$ as obtained by the fixed interference method (FIM).

$\log K_{K, \text{Li}}^{\text{Pot}}$	<-3.7	$\log K_{K, \text{Cs}}^{\text{Pot}}$	-2.5
$\log K_{K, \text{Na}}^{\text{Pot}}$	-3.2	$\log K_{K, \text{Ca}}^{\text{Pot}}$	<-3.7
$\log K_{K, \text{NH}_4}^{\text{Pot}}$	-2.1	$\log K_{K, \text{Mg}}^{\text{Pot}}$	<-3.7

Slope of linear regression: 57 mV

Response time: <30 s

Application 6 and Sensor Type ¹⁹

 Potentiometric determination K⁺ in blood serum with solvent polymeric membrane electrodes based on Potassium ionophore II.

Recommended Membrane Composition

1.00	wt%	Potassium ionophore II (60401)
67.00	wt%	2-Nitrophenyl octyl ether (73732)
31.70	wt%	Poly(vinyl chloride) high molecular weight (81392)
0.30	wt%	Potassium tetrakis(4-chlorophenyl)borate (60591)

Recommended Cell Assembly

Reference | | sample solution | | liquid membrane | 0.01 M KCl | AgCl, Ag

Electrode Characteristics and Function

 Selectivity Coefficients $\log K_{K, M}^{\text{Pot}}$ as obtained by the separate solution method (0.01 M solution of the chlorides).

$\log K_{K, \text{Na}}^{\text{Pot}}$	-3.08	$\log K_{K, \text{Ca}}^{\text{Pot}}$	-3.80
$\log K_{K, \text{Li}}^{\text{Pot}}$	-3.14	$\log K_{K, \text{Mg}}^{\text{Pot}}$	-3.92

Slope of linear regression: 59.2 mV

 Detection limit: $7.5 \cdot 10^{-6}$ M K⁺

Electrical resistance: 1 MΩ

¹⁷ K. Kimura, T. Maeda, H. Tamura, T. Shono, Potassium-selective PVC membrane electrodes based on bis- and poly(crown ether)s, *J. Electroanal. Chem.* **95**, 91 (1979)

¹⁸ H. Tamura et al., Simultaneous Determination of Sodium and Potassium in Human Urine or Serum Using Coated-Wire Ion-Selective Electrodes Based on Bis(Crown Ether)s. *Mikrochim. Acta II*, 287 (1983).

¹⁹ G.J. Moody, B.B. Saad, J.D.R. Thomas, Studies on bis(crown ether)-based ion selective electrodes for the potentiometric determination of sodium and potassium in serum, *Anal. Proc.* **26**, 8 (1989).

Application 7 and Sensor Type ^{20, 21}

Assay of K⁺ activity in diluted urine, whole blood, plasma, serum and aqueous solutions with solvent polymeric membrane electrodes based on Potassium ionophore III.

Recommended Membrane Composition

2.40	wt%	Potassium ionophore III (60397)
60.70	wt%	Bis(1-butylpentyl)adipate (02150)
36.40	wt%	Poly(vinyl chloride) high molecular weight (81392)
0.50	wt%	Potassium tetrakis(4-chlorophenyl)borate (60591)

Recommended Membrane Composition

Reference | | sample solution | | selective membrane | 0.001 M KCl | AgCl, Ag

Electrode Characteristics and Function

Selectivity Coefficients $\log K_{K, M}^{\text{Pot}}$ as obtained by the mixed solution method.

	required	found
$\log K_{K, Na}^{\text{Pot}}$	<-3.6	-3.3
$\log K_{K, Li}^{\text{Pot}}$	<-1.3	-3.8
$\log K_{K, Mg}^{\text{Pot}}$	<-2.8	-4.3
$\log K_{K, Ca}^{\text{Pot}}$	<-2.9	-4.5
$\log K_{K, NH_4}^{\text{Pot}}$		-2.1

Slope of linear regression: 58.1 mV (10⁻⁴ to 10⁻¹ KCl)

Detection limit (KCl, pure solution): $\log a_K -5.8$

(KCl, blood like electrolyte, ion background of 140 mM NaCl, 24 mM NaHCO₃, 0.6 mM MgCl₂, 1.1 mM CaCl₂): $\log a_K -4.3$

(KCl, blood like electrolyte, ion background of 130 mM NaCl, 24.8 mM TRIS, adjusted to pH 8 by 0.1 M HCl): $\log a_K -5.5$

Stability: Drift		0.01 mV/h
Standard deviation		0.03 mV
Reproducibility	(in 10 ⁻³ M KCl)	0.15 mV
	(in 10 ⁻² M KCl)	0.08 mV

Response time: 90% response time 53 ms

Electrical resistance: 3.7 MΩ

Lifetime: $\log P_{\text{TLC}}$ ionophore (required > 8.4): 10.7
 plasticizer (required >12.8): 9.3

Application 8 and Sensor Type ^{20,21}

Assay of K⁺ activity in undiluted urine, whole blood, plasma, serum and aqueous solutions with solvent polymeric membrane electrodes based on Potassium ionophore III.

Recommended Membrane Composition

2.00	wt%	Potassium ionophore III (60397)
0.20	wt%	Potassium tetrakis(4-chlorophenyl)borate (60591)
66.10	wt%	2-Nitrophenyl octyl ether (73732)
33.00	wt%	Poly(vinyl chloride) high molecular weight (81392)

Recommended Cell Assembly

Reference | | sample solution | | liquid membrane | 0.1 M KCl | AgCl, Ag

²⁰ E. Lindner, K. Tóth, J. Jeney, M. Hórvath, E. Pungor, I. Bittner, D. Agai, L. Tölke, Novel bis(crown ether)-based potassium sensor for biological applications, *Mikrochim. Acta* I, 157 (1990)

²¹ J. Jeney, K. Tóth, E. Lindner, E. Pungor, Flow-Injection Potentiometry for the Assay of Potassium in Biological Fluids, *Microchem. J.* **45**, 232 (1992).

Electrode Characteristics and Function

Selectivity Coefficients $\log K_{K, M}^{\text{Pot}}$ as obtained by the separate solution method (0.1 M solutions of the chlorides).

$\log K_{K, \text{Na}}^{\text{Pot}}$ -3.2 $\log K_{K, \text{Mg}}^{\text{Pot}}$ -4.0

$\log K_{K, \text{Li}}^{\text{Pot}}$ -3.8 $\log K_{K, \text{Ca}}^{\text{Pot}}$ -3.9

Stability: Drift 0.01 mV/h
 Standard deviation 0.03 mV
 Reproducibility 0.15 mV

Application 9 and Sensor Type ²²

Assay of K^+ activity with solvent polymeric membrane electrodes based on Potassium ionophore IV.

Recommended Membrane Composition

0.7 wt% Potassium ionophore IV ([60396](#))
 66.2 wt% 2-Nitrophenyl octyl ether ([73732](#))
 33.1 wt% Poly(vinyl chloride) high molecular weight ([81392](#))

Recommended Cell Assembly

Reference | | sample solution | | liquid membrane | 0.1 M KCl | AgCl, Ag

Electrode Characteristics and Function

Selectivity Coefficients $\log K_{K, M}^{\text{Pot}}$ as obtained by the separate solution method (0.1 M solutions of the chlorides). Conditioned in 0.1 M KCl for at least 2h.

$\log K_{K, \text{Na}}^{\text{Pot}}$ -1.4 $\log K_{K, \text{Ca}}^{\text{Pot}}$ -2.0

$\log K_{K, \text{Li}}^{\text{Pot}}$ -2.4 $\log K_{K, \text{Mg}}^{\text{Pot}}$ -2.1

$\log K_{K, \text{Cs}}^{\text{Pot}}$ -0.6 $\log K_{K, \text{NH}_4}^{\text{Pot}}$ -1.0

$\log K_{K, \text{Rb}}^{\text{Pot}}$ -0.1

²² A. Cadogan, D. Diamond, S. Cremin, M.A. McKerverey, S.J. Harris, Potassium-selective Electrode based on a Dioxacalixarene: An Example of a new Series of Ionophores, **Anal Proc.** **28**, 13 (1991).

Microelectrodes

Application 1 and Sensor Type genera 123,24; applications 24,25,26,27,28

Assay of K^+ activity in extra- and intracellular (single cell) liquids with K^+ microelectrodes based on Potassium ionophore I. Potassium ionophore I – Cocktail A shows high impedance and differs from Potassium ionophore I – Cocktail B in its selectivity coefficients.

Potassium ionophore I – Cocktail A [\(60031\)](#)

Cocktail Composition:

5.0	wt%	Potassium ionophore I (60403)
25.0	wt%	1,2-Dimethyl-3-nitrobenzene (40870)
68.0	wt%	Dibutyl sebacate (84838)
2.0	wt%	Potassium tetrakis(4-chlorophenyl)borate (60591)

Recommended Cell Assembly

Reference | sample solution | cocktail | 0.01 M KCl | AgCl, Ag

Electrode Characteristics and Function

Selectivity Coefficients $\log K_{K, M}^{\text{Pot}}$ as obtained by the separate solution method (0.1M solutions of the chlorides)²⁴:

$\log K_{K, Li}^{\text{Pot}}$	-4.0	$\log K_{K, Ca}^{\text{Pot}}$	-4.5
$\log K_{K, Na}^{\text{Pot}}$	-3.2	$\log K_{K, \text{Acetylcholine}}^{\text{Pot}}$	-2.5
$\log K_{K, Mg}^{\text{Pot}}$	-5.0		

Slope of linear regression: 57.6 ± 0.7 mV (10^{-3} to 10^{-1} M KCl)
 Electrical resistance, tip diameter ~ 1.5 μm : $\sim 10^{11}$ Ω
 Response time (90%): 30 s

Application 2 and Sensor Type general 29, applications 28, 30, 31, 32

Assay of K^+ activity in extra- and intracellular (single cell) liquids with K^+ microelectrodes based on Potassium ionophore I. Potassium ionophore I – Cocktail B shows high impedance and differs from Potassium ionophore I – Cocktail A in its selectivity coefficients.

Potassium ionophore I – Cocktail B [\(60398\)](#)

Cocktail Composition

5.0	wt%	Potassium ionophore I (60403)
93.0	wt%	1,2-Dimethyl-3-nitrobenzene (40870)
2.0	wt%	Potassium tetrakis(4-chlorophenyl)borate (60591)

²³ M. Oehme, W. Simon, Microelectrode for potassium ions based on a neutral carrier and comparison of its characteristics with a cation exchanger sensor, **Anal. Chim. Acta** **86**, 21 (1976).

²⁴ P. Wuhmann, H. Ineichen, U. Riesen-Willi, M. Lezzi, Change in nuclear potassium electrochemical activity and puffing of potassium-sensitive salivary chromosome regions during Chironomus development. **Proc. Natl. Acad. Sci.** **76**, 806 (1979).

²⁵ J.A. Coles, R.K. Orkand, Modification of potassium movement through the retina of the drone (*Apis mellifera* male) by glial uptake. **J. Physiol.** **340**, 157 (1983).

²⁶ H.L. Haas, J.G.R. Jefferys, Low-calcium field burst discharges of CA1 pyramidal neurones in rat hippocampal slices. **J. Physiol.** **354**, 185 (1984).

²⁷ U. Sonnhof, R. Förderer, W. Schneider, H. Kettenmann, Cell puncturing with a step motor driven manipulator with simultaneous measurement of displacement. **Pflügers Arch.** **392**, 295 (1982).

²⁸ D. Ammann, P. Caroni, Preparation and use of micro- and macroelectrodes for measurement of transmembrane potentials and ion activities. **Methods in Enzymol.** **172**, 136 (1989).

²⁹ D. Ammann, P. Chao, W. Simon, Valinomycin-based K^+ selective microelectrodes with low electrical membrane resistance. **Neurosci. Lett.** **74**, 221 (1987).

³⁰ H. Shimazaki, Thesis, University of Georgia, Athens, Georgia (1983).

³¹ C.J. Karwoski, E.A. Newman, H. Shimazaki, L.M. Proenza, Light-evoked increases in extracellular K^+ in the plexiform layers of amphibian retinas. **J. Gen. Physiol.** **86**, 189 (1985).

³² E. C. Reverdin, A. Illanes, J.A.S. McGuigan, Internal potassium activity in ferret ventricular muscle. **Quart. J. Exp. Physiol.** **71**, 451 (1986).

Recommended Cell Assembly

Reference | sample solution | cocktail | 0.01 M KCl | AgCl, Ag

Electrode Characteristics and Function

Selectivity Coefficients $\log K_{K, M}^{\text{Pot}}$ as obtained by the separate solution method (0.1M solutions of the chlorides) :

$\log K_{K, \text{Li}}^{\text{Pot}}$	-4.2	$\log K_{K, \text{Ca}}^{\text{Pot}}$	-4.9
$\log K_{K, \text{Na}}^{\text{Pot}}$	-3.9	$\log K_{K, \text{Acetylcholine}}^{\text{Pot}}$	-3.5
$\log K_{K, \text{Mg}}^{\text{Pot}}$	-4.6		

Slope of linear regression: 57.8 ± 1.2 mV at 20°C (10^{-4} to 10^{-1} M KCl)

Detection limit (KCl, ion background of 140 mM Na⁺): $\log a_K \sim -4.8$

Electrical resistance: tip diameter $\sim 1 \mu\text{m}$: $1.2 \cdot 10^{10} \Omega$

Response time: time constant of electrode response $< 1 \text{ s}$ ³⁰

Application 3 and Sensor Type^{28,33,34}

Extra- und intracellular measurement of K⁺ activities. Despite the poor rejection of Na⁺ and the relatively high preference of organic cations, this microelectrode is preferentially applied in physiological studies because of its low resistance and short response time.

Cocktail Composition

3.0 wt% Potassium tetrakis(4-chlorophenyl)borate ([60591](#))
 97.0 wt% 1,2-Dimethyl-3-nitrobenzene ([40870](#))

Recommended Cell Assembly

Reference | sample solution | cocktail | 2.0 M KCl, agar | AgCl, Ag

Electrode Characteristics and Function

Selectivity Coefficients $\log K_{K, M}^{\text{Pot}}$ as obtained by the separate solution method (0.1M solutions of the chlorides) :

$\log K_{K, \text{Li}}^{\text{Pot}}$	-3.2	$\log K_{K, \text{Ca}}^{\text{Pot}}$	-2.6
$\log K_{K, \text{Na}}^{\text{Pot}}$	-1.8	$\log K_{K, \text{Mg}}^{\text{Pot}}$	-3.0
$\log K_{K, \text{NH}_4}^{\text{Pot}}$	0.3	$\log K_{K, \text{Ba}}^{\text{Pot}}$	-2.0
$\log K_{K, \text{H}}^{\text{Pot}}$	-1.7	$\log K_{K, \text{Acetylcholine}}^{\text{Pot}}$	3.6

Slope of linear regression: 58.1 ± 0.5 mV at 22°C (10^{-4} to 10^{-1} M KCl)

Practical pH measuring range: 4-10

Electrical resistance: tip diameter $\sim 1 \mu\text{m}$: $1.7 \cdot 10^9 \Omega$

Response time (95%): $< 0.25 \text{ s}$

³³ D. Ammann, Ion-Selective Microelectrodes. Principles, Design and Application, Springer-Verlag, Berlin, Heidelberg, New York, Tokyo (1986).

³⁴ R. Wen, B. Oakley, Ion-selective microelectrodes suitable for recording rapid changes in extracellular ion concentration. **J. Neurosci. Meth.** **31**, 207 (1990).

C. Nicholson, Ion-selective microelectrodes and diffusion measurements as tools to explore the brain cell microenvironment. **J. Neurosci. Meth.** **48**, 199 (1993).

Ion-selective Field Effect Transistors

Application 1 and Sensor Type ^{35,36,37}

Assay of K⁺ activity with Urushi matrix ion-selective field effect transistors of good durability based on Potassium ionophore I.

Recommended Membrane Composition

0.50	wt%	Potassium ionophore I (71732)
49.25	wt%	Bis(2-ethylhexyl) phthalate (80030)
0.25	wt%	Potassium tetrakis(4-chlorophenyl)borate (60591)
50.00	wt%	Urushi (polymer from lacquer tree)

Electroanalytical Characteristics

Selectivity Coefficients $\log K_{K, M}^{\text{Pot}}$ as obtained by the mixed solution method

$\log K_{K, \text{Na}}^{\text{Pot}}$	-3.3	$\log K_{K, \text{NH}_4}^{\text{Pot}}$	-1.7
$\log K_{K, \text{Ca}}^{\text{Pot}}$	-4.5	$\log K_{K, \text{Mg}}^{\text{Pot}}$	-4.6

Slope of linear regression: 53 mV (10⁻⁴ to 1 M Na⁺).

Application 2 and Sensor Type ^{36,37,38}

Assay of K⁺ activity with silicon rubber matrix ion-selective field effect transistors based on Potassium ionophore I.

Recommended Membrane Composition

3.0	wt%	Potassium ionophore I (71732)
88.0	wt%	Siloprene K 1000 (85417)
9.0	wt%	Siloprene crosslinking agent K 11 (85418)

Electroanalytical Characteristics

Selectivity coefficient $\log K_{\text{Na}, M}^{\text{Pot}}$ <-3.7 as obtained by the fixed interference method (0.1 M NaCl)

Lifetime: ~2 months

Ion-selective Conductometric Microsensors

Application ³⁹

Assay of K⁺ activity with ion-selective conductometric microsensors (ISCOM). Detection is accomplished by measurement of the bulk conductance of the solvent polymeric membrane based on Potassium ionophore I.

Recommended Membrane Composition

5.0	wt%	Potassium ionophore I (60403)
30.0	wt%	Poly(vinyl chloride) high molecular weight (81392)
65.0	wt%	2-Nitrophenyl octyl ether (73732)

Selectivity Coefficients $\log K_{K, M}^{\text{Pot}}$ as obtained by the mixed solution method

$\log K_{K, \text{Na}}^{\text{Pot}}$	-2.6	$\log K_{K, \text{Cs}}^{\text{Pot}}$	-0.5
$\log K_{K, \text{Li}}^{\text{Pot}}$	-3.0	$\log K_{K, \text{Rb}}^{\text{Pot}}$	0.6
$\log K_{K, \text{NH}_4}^{\text{Pot}}$	-1.3		

³⁵ S.I. Wakida, M. Yamane, K. Higashi, K. Hiro, Y. Ujihara, Urushi matrix sodium, potassium, calcium and chloride-selective field-effect transistors, *Sens. Actuators B1*, 412 (1990).

³⁶ J. Janata, R. Huber, *Ion-Selective Electrode Rev.* 1, 31 (1979).

³⁷ P. Bergveld, The operation of an ISFET as an electronic device, *Sensors and Actuators* 1, 17 (1981).

³⁸ P. Van der Wal, M. Skowronska-Ptasinska, A. van den Berg, P. Bergveld, E.J.R. Sudhölter, D.N.R. Reinhoudt, *Anal. Chim. Acta* 231, 41 (1990).

³⁹ A.A. Shul'ga, B. Ahlers, K. Cammann, Ion-selective conductometric microsensors based on the phenomenon of specific salt extraction, *J. Electroanal. Chem.*, 395, 305 (1995).

Membrane specific conductivity: 0.5 to 5 $\mu\text{S/cm}$
 Frequency range: 0.5 to 20 kHz
 Membrane thickness: ~2 mm
 Detection limit: $>10^{-6} \text{ M K}^+$
 Response time: ~1 s

Chemically Modified Electrodes

Application and Sensor Type

Assay of K^+ activity with photo-cured polymer membrane electrodes for flow-injection analysis, based on Potassium ionophore I,

Cocktail Composition

37.60	wt%	Ebecryl 600 (45351)
14.20	wt%	Uvecryl P36 (94482)
24.60	wt%	Bis(1-butylpentyl)decane-1,10-diyl diglutarate (30585)
3.80	wt%	Potassium ionophore I (60403)
19.20	wt%	1,6-Hexanediol diacrylate (52812)
0.60	wt%	Potassium tetrakis(4-chlorophenyl)borate (60591)

Electrode Characteristics and Function

Selectivity Coefficients $\log K_{K, M}^{\text{Pot}}$ determined by the fixed interference method.

$\log K_{K, \text{NH}_4}^{\text{Pot}}$	-1.8	$\log K_{K, \text{Ca}}^{\text{Pot}}$	-2.9
$\log K_{K, \text{Na}}^{\text{Pot}}$	-2.7	$\log K_{K, \text{Mg}}^{\text{Pot}}$	-2.7
$\log K_{K, \text{Li}}^{\text{Pot}}$	-2.4	$\log K_{K, \text{Cu}}^{\text{Pot}}$	-2.1

Slope of linear regression: 59.8 mV (10^{-5} to 10^{-1} M K^+); steady-state measurements
 46.8 mV (10^{-4} to 10^{-1} M K^+); flow-injection measurements

Optical Transduction

Application 1 and Sensor Type ^{40, 41, 42}

Assay of K⁺ activity in aqueous pH buffered solutions and in diluted blood plasma with solvent polymeric optode membranes based on Chromoionophore I (ETH 5294) and Potassium ionophore I.

Recommended Membrane Composition

0.48	wt%	Chromoionophore I (27086)
1.00	wt%	Potassium ionophore I (60403)
0.44	wt%	Potassium tetrakis(4-chlorophenyl)borate (60591)
66.05	wt%	Bis(1-ethylhexyl)sebacate (84818)
32.03	wt%	Poly(vinyl chloride) high molecular weight (81392)

Recommended pH Buffer

0.16 M sodium acetate, adjusted with acetic acid to pH 5.1 for recording the calibration curve to pH 5.5 for diluting blood plasma samples.⁴³

Optode Characteristics and Function

Selectivity Coefficients $\log K_{K,M}^{\text{Opt}}$ as obtained by the fixed interference method in pH buffered solutions.

$\log K_{K,Na}^{\text{Opt}}$	-3.5	$\log K_{K,Ca}^{\text{Opt}}$	-3.7
$\log K_{K,Mg}^{\text{Opt}}$	-4.0	$\log K_{K,Li}^{\text{Opt}}$	-3.7

Application 2 and Sensor Type ⁴⁴

Assay of K⁺ activity in aqueous pH buffered solution and in human blood plasma with solvent polymeric optode membranes based on Chromoionophore I (ETH 5294) and Potassium ionophore III.

Recommended Membrane Composition

0.52	wt%	Chromoionophore I (27086)
1.04	wt%	Potassium ionophore III (60397)
0.48	wt%	Potassium tetrakis(4-chlorophenyl)borate (60591)
65.97	wt%	Bis(2-ethylhexyl)sebacate (84818)
31.99	wt%	Poly(vinyl chloride) high molecular weight (81392)

Recommended pH Buffer

Citrate buffer of pH 6.5 (0.002 M citric acid adjusted with 0.1 M NaOH)

Optode Characteristics and Function

Selectivity Coefficients $\log K_{K,M}^{\text{Opt}}$ as obtained by the separate solution method.

$\log K_{K,Na}^{\text{Opt}}$	-3.0	$\log K_{K,Cs}^{\text{Opt}}$	-2.0
$\log K_{K,Rb}^{\text{Opt}}$	-1.1		

⁴⁰ Fluka H58166H: K. Seiler, Ion-selective Optode Membranes, monograph, describing theory, preparation and application of ion-selective optode membranes as well as recent developments in this field. With 237 references. published by Fluka Chemie GmbH, Buchs, Switzerland (1993)

Fluka H58165H: K. Seiler, Ionenselektive Optodenmembranen, dt. Monographie, herausgegeben von Fluka Chemie GmbH, Buchs, Switzerland (1993)

⁴¹ U.E. Spichiger, K. Seiler, K. Wang, G. Suter, W.E. Morf, W. Simon, Optical quantification of sodium, potassium and calcium ions in diluted human plasma based on ion-selective liquid membranes. International Congress on Optical Sciences and Engineering, The Hague, The Netherlands, 11 - 15 March 1991. SPIE Proceedings Nr. 1510, pp. 118-130 (1991).

⁴² U.E. Spichiger, D. Freiner, E. Bakker, T. Rosatzin, W. Simon Optodes in clinical chemistry: potential and limitations, **Sens. Actuators B11**, 263 (1993).

⁴³ D.D. Perrin, B. Dempsey, Buffers for pH and Metal Ion Control. Chapman & Hall, London, New York (1983).

⁴⁴ K. Wang, K. Seiler, W.E. Morf, U.E. Spichiger, W. Simon, E. Lindner, E. Pungor, Characterisation of Potassium-Selective Optode Membranes Based on Neutral Ionophores and Application in Human Blood Plasma, **Anal. Sci.** **6**, 715 (1990)

Application 3 and Sensor Type⁴⁵

Assay of K⁺ activity in aqueous pH buffered solutions with solvent polymeric fluorescent optode membranes based on Chromoionophore I (ETH 5294) and Potassium ionophore I. LEDs or diode lasers may be used as light sources.

Recommended Membrane Composition

2.98	wt%	Chromoionophore I (27086)
13.43	wt%	Potassium ionophore I (60403)
2.98	wt%	Potassium tetrakis(4-chlorophenyl)borate (60591)
44.78	wt%	Bis(2-ethylhexyl)sebacate (84818)
17.91	wt%	WM-3 plasticizer
17.92	wt%	Poly(vinyl chloride) high molecular weight (81392)

Recommended pH Buffer

0.1 M TRIS at pH 7.38

Optode Characteristics

Measuring range:	$5 \cdot 10^{-6}$ to 10^{-1} K ⁺
Detection limit:	$\sim 5 \cdot 10^{-6}$ M K ⁺
Membrane thickness:	~ 1 μ m
Response time:	~ 1 to 3 min

⁴⁵ H. He, G. Uray, O. Wolfbeis, An Enantio-Selective Optode for the β -Blocker Propranolol. **Proc. SPIE-Int. Soc. Opt. Eng.** **1368**, 165 (1990).