

DECLARATION IN SUPPORT OF A  
CONVENTION APPLICATION FOR A PATENTAUSTRALIA  
CONVENTION  
STANDARD  
& PETTY PATENT  
DECLARATIONIn support of the Convention Application made for a  
patent for an invention entitled:

Title of invention

Electrochemical Electrodes

Full name(s) and  
address(es) of  
Declarant(s)

I/We John Michael Harker, Deputy Secretary

of Health Laboratory Service Board  
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UNITED KINGDOM

do solemnly and sincerely declare as follows:-

Full name(s) of  
Applicant(s)~~1. I am/We are the applicant(s) for the patent~~*(or, in the case of an application by a body corporate)*

1. I am/We are authorised by

Health Laboratory Service Board

the applicant(s) for the patent to make this declaration on  
its/their behalf.2. The basic application(s) as defined by Section 141 of the  
Act was/were made

in Great Britain

Basic Country(ies)

Priority Date(s)

on 24 November 1987

Basic Applicant(s)

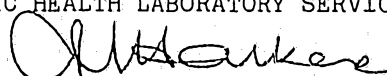
by Health Laboratory Service Board

Full name(s) and  
address(es) of  
inventor(s)~~3. I am/We are the actual inventor(s) of the invention referred  
to in the basic application(s)~~*(or where a person other than the inventor is the applicant)*3. Martin Charles Wiles, David Jorge Schiffrin  
and David John Clarkeof 24 Roselands Gardens, Southampton SO2 1QG; 10 Nutshalling  
Avenue, Rownhams, Southampton SO1 8AY and "Carefree",  
Rivermead, Idmiston, Salisbury all in United Kingdom  
(respectively)is/are the actual inventor(s) of the invention and the facts upon  
which the applicant(s) is/are entitled to make the application areas follows: Health Laboratory Service Board is entitled by  
Contract of Employment between the inventor David John Clarke  
as employee and Health Laboratory Service Board as employer,  
as a person who would be entitled to have the patent assigned  
to it if a patent were granted upon an application made by  
this inventor and Health Laboratory Service Board is the  
assignee of the inventors Martin Charles Wiles and David  
Jorge Schiffrin.4. The basic application(s) referred to in paragraph 2 of this  
Declaration was/were the first application(s) made in a Convention  
country in respect of the invention(s) the subject of the application.

Declared at London this 10th day of August 1989

PUBLIC HEALTH LABORATORY SERVICE BOARD

BY:



Signature of Declarant(s)

Set out how Applicant(s)  
derive title from actual  
inventor(s) e.g. The  
Applicant(s) is/are the  
assignee(s) of the  
invention from the  
inventor(s)

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ELECTROCHEMICAL ELECTRODES
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- (56) Prior Art Documents  
EP 186210  
US 4431508  
EP 24191
- (57) Claim

1. An electrochemical reference element suitable for use with an organic liquid, comprising a metal electrode and a solid electrolyte in contact with the electrode, the electrolyte comprising a salt of an organic ion with the metal of the electrode, the salt being substantially insoluble in said organic liquid and the anion being sufficiently soluble in said organic liquid to form an electrochemical couple.

3. An element according to Claim 1, wherein said anion is selected ~~ed~~ from the group of aryloxyborates, i.e. anions of the general formula  $(ArO)_4^-B^*$ , wherein each ArO group, which may be the same or different, represents an aryloxy group having up to 20 carbon atoms, optionally substituted by one or more halogen atoms or nitro groups.

8. An element according to any one of the preceding claims, wherein the metal of the electrode is selected from the group consisting of silver, cadmium, cobalt, iron, lead and nickel.

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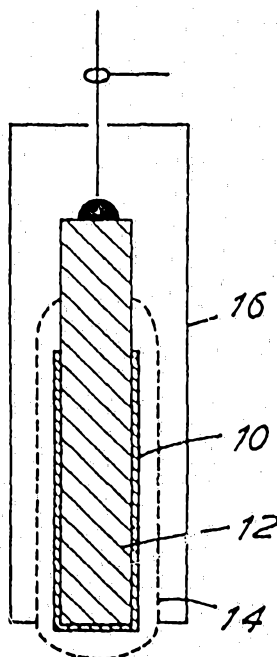
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(54) Title: ELECTROCHEMICAL ELECTRODES



(57) Abstract

An electrochemical reference element is proposed having a metal electrode such as Ag coated with the tetraphenyl (TPB) salt of the metal. The element may form the internal reference of an ion selective electrode with an ion selective membrane carried directly upon the TPB coating. The element provides a thermodynamically reversible couple suitable for use in a non-aqueous environment.

ELECTROCHEMICAL ELECTRODES

This invention relates to electrochemical electrodes and particularly to electrochemical reference elements for use in solvents other than water.

A good example of such usage is ion selective electrodes which are based on organic ion exchangers or neutral carriers. The active material can be in liquid form held in an inert porous membrane but more conveniently the active material is incorporated within a suitably plasticised polymer substrate. In the early designs, the half cell was completed by immersing a silver wire in an internal reference solution of the appropriate chloride salt (potassium for a potassium ion selective electrode) forming a silver/silver chloride internal reference electrode. The potential of this half cell is usually measured against a reference electrode, with the silver/silver chloride reference electrode being usually employed. It will be understood that the ionic current/potential across the membrane is thereby converted into an electronic current/potential at the internal reference electrode, which can be measured. The advantages of using a thermodynamically-definable reversible electrode system as the internal reference electrode will be apparent.

There are clear advantages in developing solid state versions of these ion selective electrodes and considerable efforts have been made in developing so-called "coated wire" electrodes. Commonly, the aqueous internal reference solution is incorporated into a hydrophilic polymer layer such as polyvinyl alcohol (PVA). These devices must be very carefully constructed. For example, in order to prevent osmotic

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effects across the membrane, this must be introduced when the water content of the PVA layer is within a fixed range. Ideally, this requires coating to be carried out at fixed relative humidities.

In some prior proposals, the use of a reversible electrode has been abandoned with, for example, the membrane being coating directly onto platinum. Even though potentials are measured using very high input impedance volt meters, the ionic to electronic currents are still likely to be high enough to cause problems of drift, noise and lack of reproducibility, in the absence of any thermodynamically reversible electrode. Surface oxides and contamination of the metal can also lead to systematic errors.

A further approach that has been adopted in an attempt to solve this problem is the use of oxidation/reduction processes at noble metal electrodes (for example ferrocene/ferrocenium at a platinum electrode). However, whilst this proposal achieves buffering of the electronic part of the couple, this tends to be unstable.

It is an object of one aspect of this invention to provide an improved ion selective electrode in which the above difficulties are to a significant extent overcome.

Accordingly, the present invention consists in one aspect in an electrochemical reference element suitable for use with an organic liquid, comprising a metal electrode and a solid electrolyte in contact with the electrode, the electrolyte comprising a salt of an organic ion with the metal of the electrode, the salt being substantially insoluble in said organic liquid and the anion being sufficiently soluble in said organic liquid to form an electrochemical couple.

Preferably, said anion has a hydrophobic aromatic group.

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One class of anions comprises anions derived from aryloxyborates, i.e. anions of the general formula  $(\text{ArO})_4^- \text{B}^+$ , wherein each ArO group, which may be the same or different, represents an aryloxy group having up to 20 carbon atoms, optionally substituted by one or more halogen atoms or nitro groups. The aryl group Ar may for example be a phenyl or naphthyl group which may be substituted by one or more hydrocarbyl groups having up to 6 carbon atoms. In a particularly preferred class of compounds, Ar is selected from phenyl and 4-halo phenyl.

Another class of anions includes anions derived from hydroxy-substituted aromatic compounds, for example phenols and substituted phenols and naphthols and substituted naphthols. Such compounds include mono-hydroxy phenols and mono-hydroxy naphthols each of which may contain one or more electron-withdrawing groups, for example  $\text{NO}_2$  groups, as in picrate anions and picraminate anions.

Preferably the metal is selected from the group consisting of silver, cadmium, cobalt, iron, lead and nickel.

The reference element according to this invention may be used within an ion selective electrode with the solid electrolyte establishing contact with an ion selective membrane.

Problems occur with the silver/silver chloride electrode (and the other commonly used reference electrode - calomel), in applications where it is required to operate in non-aqueous solvents/solutions. Since these reference electrodes require an aqueous salt solution (e.g. KCl NaCl), it is necessary to provide an aqueous bridge solution from the electrode and a liquid junction to the non-aqueous solvent. This is a complicated arrangement which can lead to difficulties.

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The reference element of this invention can accordingly be used with advantage within a reference electrode for use in non-aqueous solutions. The skilled man will appreciate that there are wide variety of further applications for the reference element according to this invention, including electrodes for sensing proteins, cells or viruses.

A preferred form of reference element according to this invention is silver/silver tetraphenylborate and there will now be described by way of example two methods for producing a electrode in this form.

#### METHOD 1:

- Heat platinum gauze in a hydrogen/oxygen flame to clean the surface
- Dip the clean platinum gauze in silver oxide powder and flame gently until the oxygen has been removed and a greyish colour remains.  
Repeat this step until a sufficiently thick layer of porous silver has formed on the platinum gauze.
- Electrolyse the porous silver coated platinum gauze in a saturated solution of tetraphenylborate in 1, 2 dichlorethane (or other appropriate solvent) for 12 to 18 hours at low current (approx 1mA).

#### METHOD 2:

- Heat silver wire in a flame to clean (as above)
- Electrolyse the cleaned silver wire in a saturated TPB solution for 12 to 18 hours at low current (as above)

In the case of ion selective electrodes, the membrane can be coated directly onto the Ag/AgTPB electrode. This not only provides a reversible electrode (the electronic part) without an internal aqueous filling solution, but provides ionic buffering (as well as electronic buffering) within the device.

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TPB<sup>-</sup> itself can be used as an ion exchanger in ion selective electrodes. More commonly, it is also used as a counter ion with membranes using carrier-type sensing ligands (e.g. for K,  $\text{NHC}_4$ , Na, Ca, Mg). In these cases the membrane compositions do not need to be significantly changed for use with the internal reference electrode according to this invention. This does not mean, however, that alternative neutral carrier membranes cannot be developed with the addition of TPB.

The invention will further be described by way of example with reference to accompanying drawings in which:

Figures 1, 2 and 3 are diagrams illustrating alternative forms of ion selective electrodes according to this invention;

Figure 4 is a cyclic voltamogram of an Ag/Ag TPB electrode;

Figure 5 is a plot of the response of an Ag/Ag TPB; electrode to changes in concentration of the anion;

Figure 6 shows plots of measured potential against time for respective like ion selective electrodes of the form shown in Figure 1 in samples subject to defined step changes in ion concentration, and

Figure 7 is an electrode calibration plot.

In the arrangement shown in Figure 1, an AgTPB applied to an Ag wire 12, for example by Method 2 above. An ion selective membrane 14 is then applied over the AgTPB coating and the assembly suitably encapsulated as shown at 16.

The arrangement of Figure 2 is similar but includes a silver plate 18 in place of the silver wire of the Figure 1 embodiment. Other components are shown with the same reference numerals, primed.

In the arrangement shown in Figure 3, the Ag electrode is formed by an Ag film 20 suitably deposited upon a plastics or ceramic substrate 22. The AgTPB coating 24 is then applied over the Ag film so as completely to cover the same. A permselective membrane 26 covers the AgTPB coating and a ring of encapsulation material 28 is applied so as to avoid edge effects.

Utilising the structure of Figure 3, a plurality of ion selective electrodes may be formed on the same substrate using, for example, printing processes such as screen printing. A number of electrodes of the same selectivity may be incorporated to accommodate failure of any individual device or for the purpose of increasing accuracy by allowing simultaneous multiple measurement, with an appropriate statistical processing technique.

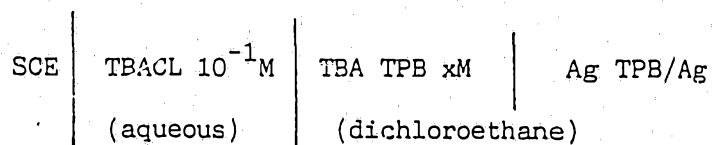
Alternatively, one or more of the printed electrode devices may be a reference electrode against which the potential of the working ion selective half cells may be measured. The reference electrode may be of a conventional type or may preferably be constructed in the manner of an ion selective electrode with, for example, the neutral carrier of the membrane omitted so that the electrode does not respond to the ionic species of interest and serves as a reference. It will be understood that the location in this way of the reference electrode in close proximity to the selective electrode will improve,

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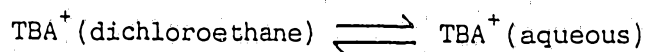
for example, common mode rejection. Alternatively, the reference electrode may be constructed as an ion selective electrode to act additionally to null electrochemical interference. For instance, in the case where the selective electrode responds both to the ionic species of interest and to an interfering species, the reference electrode may be arranged to respond to the or each interferent.

Referring to Figure 4, a cyclic voltamogram is shown, produced by varying the potential applied to a Ag/Ag TPB electrode and measuring the current. This demonstrates the reversibility of the electrode. The compressed form of the plot is explained by the low conductivity of the non-aqueous solvent solution of the TPB used in making the measurements ( $10^{-3}$ M tetrabutyl ammonium tetraphenyl borate in 1,2-dichloroethane).

There is shown in Figure 5 a plot of the measured potential of an Ag/Ag TPB electrode against concentration. Measurements were taken against a saturated calomel electrode using the tetrabutyl ammonium (TBA) cation as a bridge between the aqueous and non-aqueous phases. In particular, the cell can be defined as:-



The plot is "super-Nernstian" in that a slope of around -120mV is observed rather than -60mV as expected for a monovalent anion. This can be explained by the contribution from the activity of the TBA cation in the liquid junction equilibrium:-



Using the structure illustrated in Figure 1 and conventional membranes, ion selective electrodes according to this invention were prepared with selectivity to potassium. A batch of like electrodes was used to measure the concentration (activity) of a sample of potassium ion, the sample being subject to step-wise concentration changes. The experimental results are plotted in Figure 6. It will be seen that the electrodes generally exhibit fast response and reasonable stability.

Figure 7 presents the response of the same batch of electrodes in a form in which the calibration points of the electrodes can be assessed in terms of sensitivity or slope expressed in change in potential in millivolts per decade change in concentration or activity and offset expressed in millivolts.

Ammonium, sodium, hydrogen, lithium, calcium, magnesium, nitrate, chloride, phosphate and other inorganic cation and anion selective electrodes may be constructed by coating the appropriate permselective membrane on to the Ag/AgTPB electrodes. In a similar fashion the Ag/AgTPB electrode may also be used for organic cation and anion selectivities. Electrodes based on the binding of proteins, DNA, RNA, viruses and cells to an affinity ligand incorporated into the appropriate membrane may also advantageously use the Ag/AgTPB electrode.

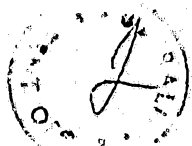
This invention has been more particularly described with reference to the Ag/Ag TPB electrode and this is the preferred form. It is considered, however, that TPB electrodes could be formed with other non-noble metals. Moreover, whilst TPB has the advantage of being an anion currently used within certain ion exchanger membranes, it is considered that electrodes according to the invention can usefully be constructed using other solvent soluble anions which form

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an insoluble salt of a metal. Preferred metal salts other than TPB are of tetrakis (4-fluorophenyl) borate, tetrakis (4-chlorophenyl) borate, dipicrylamine, picrate and dicarbonyl cobaltate. Preferred metals in addition to silver are cadmium, cobalt, iron, lead and nickel.

CLAIMS

1. An electrochemical reference element suitable for use with an organic liquid, comprising a metal electrode and a solid electrolyte in contact with the electrode, the electrolyte comprising a salt of an organic ion with the metal of the electrode, the salt being substantially insoluble in said organic liquid and the anion being sufficiently soluble in said organic liquid to form an electrochemical couple.
2. An element according to Claim 1, wherein said anion has a hydrophobic aromatic group.
3. An element according to Claim 1, wherein said anion is selected from the group of aryloxyborates, i.e. anions of the general formula  $(\text{ArO})_4^- \text{B}^+$ , wherein each ArO group, which may be the same or different, represents an aryloxy group having up to 20 carbon atoms, optionally substituted by one or more halogen atoms or nitro groups.
4. An element according to Claim 3, wherein the aryl group Ar is phenyl or naphthyl which may be substituted by one or more hydrocarbyl groups having up to 6 carbon atoms.
5. An element according to Claim 4, wherein Ar is selected from phenyl and 4-halo phenyl.



6. An element according to Claim 1, wherein said anion is selected from the group of hydroxy-substituted aromatic compounds.

7. An element according to Claim 6, wherein said anion is selected from the group of phenols and substituted phenols and naphthols and substituted naphthols.

8. An element according to any one of the preceding claims, wherein the metal of the electrode is selected from the group consisting of silver, cadmium, cobalt, iron, lead and nickel.

9. An electrochemical reference element comprising a metal conductor coated with a tetraphenyl borate salt of said metal forming a solid electrolyte.

10. An ion selective electrode comprising a reference element according to any one of the preceding claims with the solid electrolyte establishing contact with an ion selective membrane.

11. An electrochemical reference element for use with an organic liquid, substantially as hereinbefore described with reference to Method 1 or Method 2 or any one of Figs 1 to 3.

DATED this TENTH day of MAY 1991  
Public Health Laboratory Service Board

Patent Attorneys for the Applicant  
SPRUSON & FERGUSON



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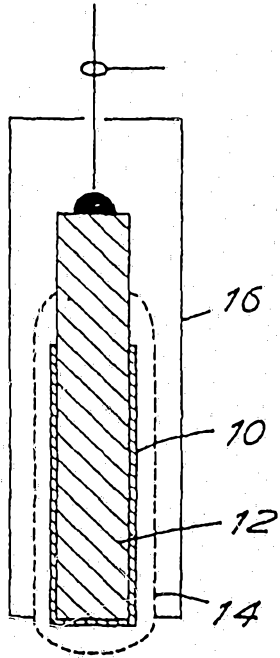


FIG. 1

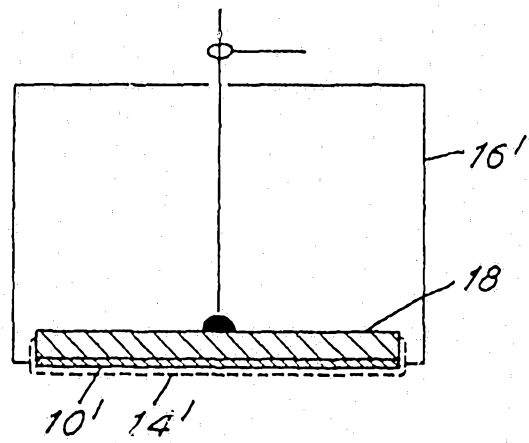


FIG. 2

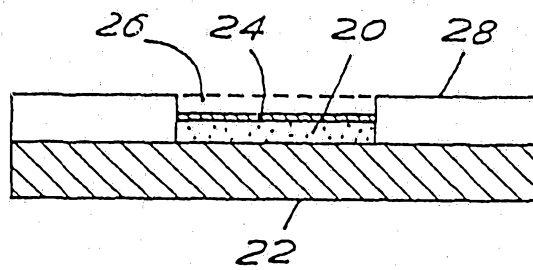
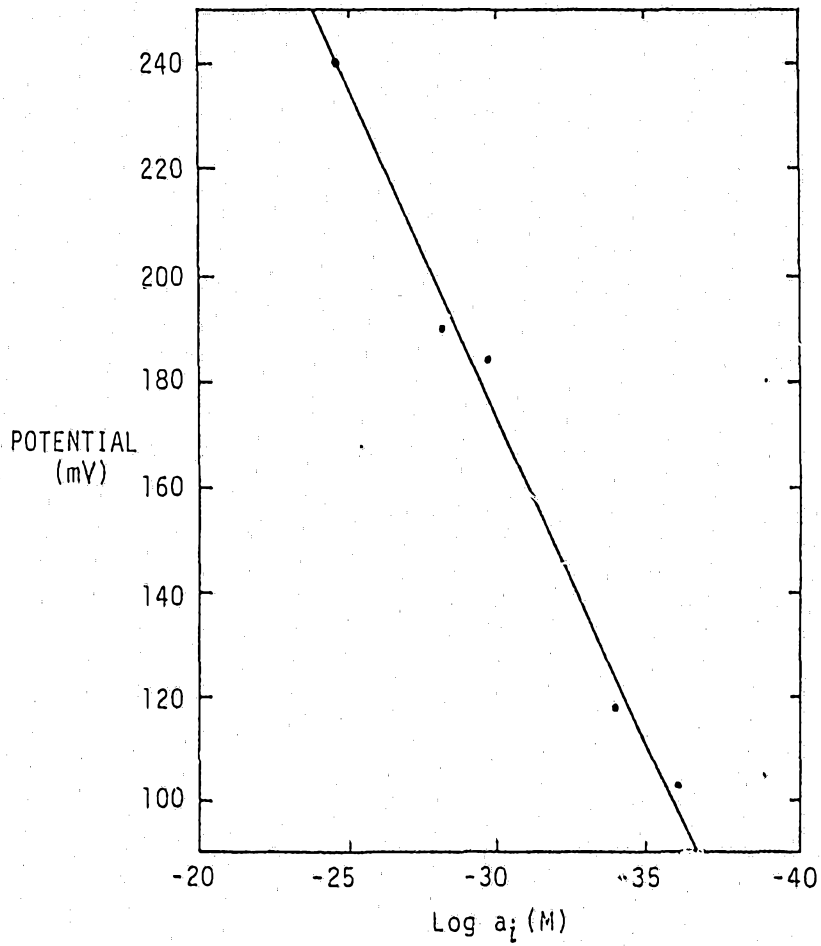
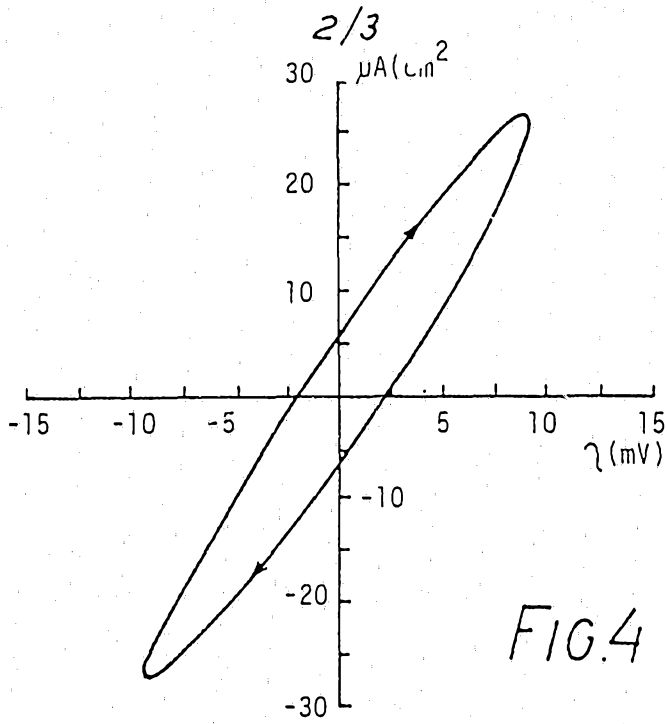


FIG. 3



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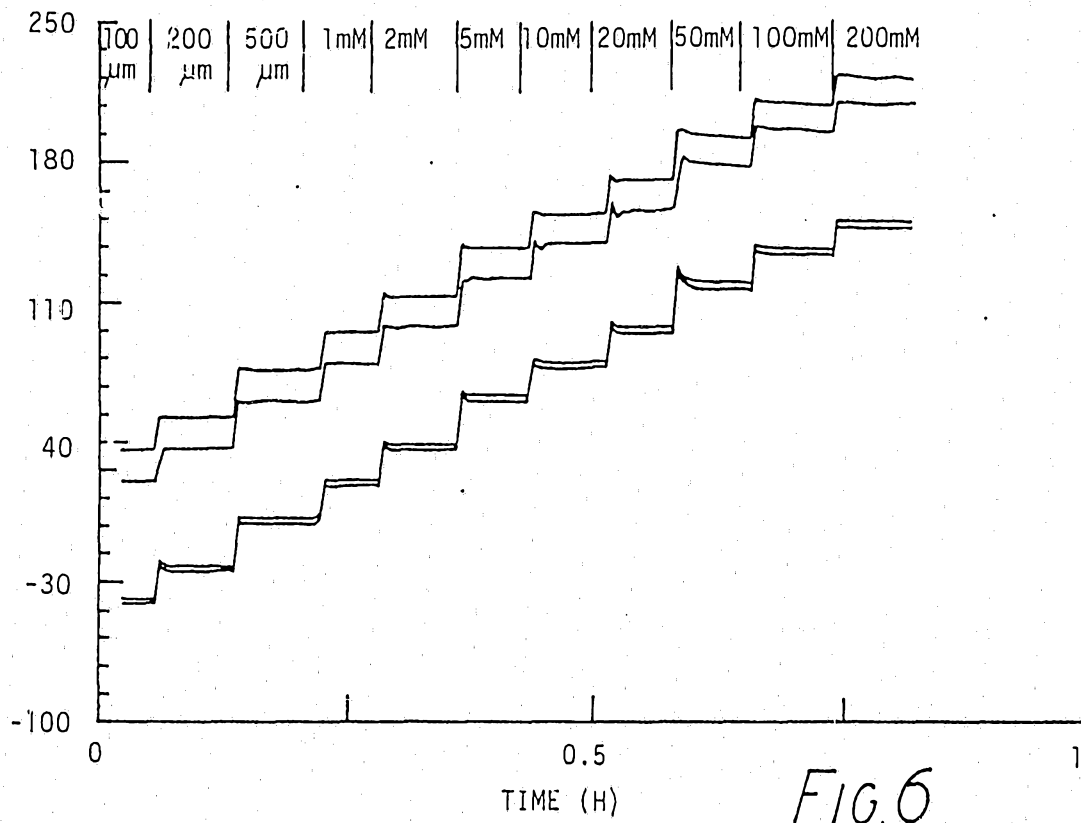


FIG. 6

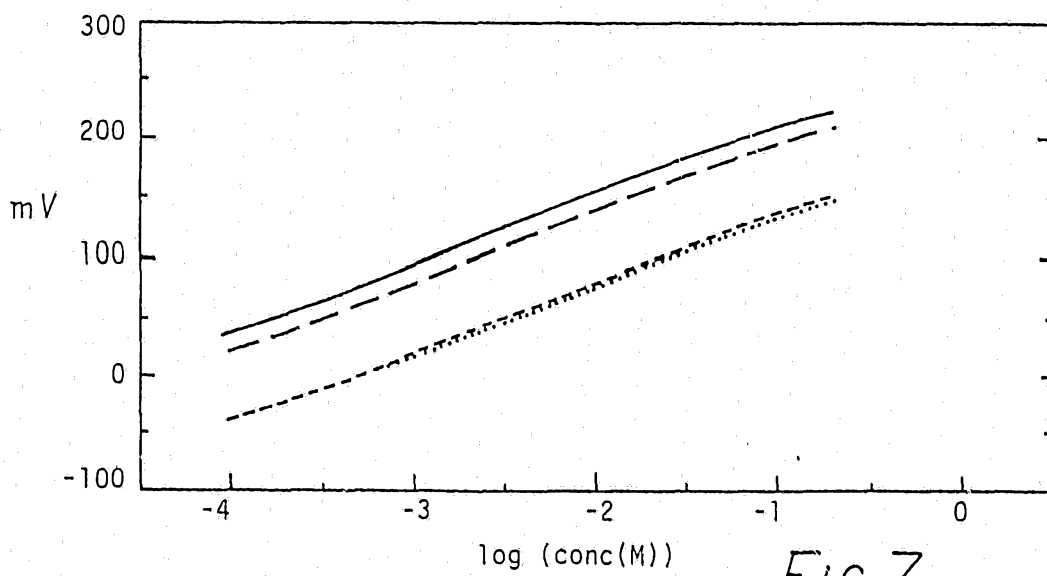



FIG. 7

# INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 88/00992

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (If several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC <sup>4</sup> : G 01 N 27/30		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>7</sup>		
Classification System	Classification Symbols	
IPC <sup>4</sup>	. G 01 N	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT <sup>9</sup></b>		
Category <sup>10</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
A	EP, A, 0186210 (S. YAMAGUCHI) 2 July 1986, see front page	1
	--	
A	US, A, 4431508 (H.M. BROWN) 14 February 1984, see front page	1
	--	
A	US, A, 3598713 (G.B. CORNING) 10 August 1971, see claims 4,5	1
	--	
A	EP, A, 0024191 (S.H. KIM) 25 February 1981, see front page	1
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<p><sup>10</sup> Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"A" document member of the same patent family</p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
8th February 1989	- 1. 03. 89	
International Searching Authority	Signature of Authorized Officer	
EUROPEAN PATENT OFFICE	 <b>P.C.G. VAN DER PUTTEN</b>	

ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO.

GB 8800992  
SA 25263

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 16/02/89. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A- 0186210	02-07-86	JP-A- 61155949	15-07-86
		JP-A- 61194343	28-08-86
		JP-A- 61213660	22-09-86
		JP-A- 61213662	22-09-86
		JP-A- 61251764	08-11-86
US-A- 4431508	14-02-84	None	
US-A- 3598713	10-08-71	NL-A- 7007959	07-12-70
		DE-A- 2024636	10-12-70
		FR-A- 2049818	26-03-71
		GB-A- 1284476	09-08-72
EP-A- 0024191	25-02-81	JP-A- 56033538	04-04-81
		US-A- 4263343	21-04-81
		CA-A- 1151107	02-08-83