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NONAQUEOUS ELECTROLYTES

The present invention relates to an organic electrolyte solution for use in a high energy electrochemical cell comprising a solute dissolved in a mixture of a dioxolane-based solvent and an acyclic ether solvent.

The development of high energy battery systems requires the compatibility of an electrolyte possessing desirable electrochemical properties with highly reactive anode materials, such as lithium and sodium, and the efficient use of high energy density cathode materials, such as FeS_2 . The use of aqueous electrolytes is precluded in these systems, as the anode materials are sufficiently active to react with water chemically.

It has, therefore, been necessary, in order to realise the high energy density obtainable through use of these highly reactive anodes and high energy density cathodes, to turn to the investigation of nonaqueous electrolyte systems and, more particularly, to nonaqueous organic electrolyte systems.

The term "nonaqueous organic electrolyte", in the prior art, refers to an electrolyte which is composed of a solute, for example, a salt of a complex salt of Group I-A, Group II-A or Group III-A elements of the Periodic Table, dissolved in an appropriate nonaqueous organic solvent. Conventional nonaqueous solvents include propylene carbonate, 1,2-dimethoxyethane, tetrahydrofuran, ethylene carbonate, 3-methyl-2-oxazolidone and 3,5-dimethylisoxazole.

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A multitude of solutes is known and recommended for use in such systems, but the selection of a suitable solvent has been particularly troublesome, since many of those solvents which are used in the preparation of electrolytes sufficiently conductive to permit effective ion migration through the solution are reactive with the highly reactive anodes described above.

Most investigators in this area, in search of suitable solvents, have concentrated on aliphatic and aromatic nitrogen- and oxygen-containing compounds. The results of this search have not been entirely satisfactory, as many of the solvents investigated still could not be used effectively with extremely high energy density cathode materials, and were sufficiently corrosive to lithium anodes to prevent efficient performance over any length of time.

US-A-4,071,665 discloses high energy density galvanic batteries having high utilisation of active electrode materials such as lithium anodes, cathode depolarisers reducible by the anodes, such as cupric sulphide, and electrolytes comprising a dioxolane as solvent and up to about 20 weight percent of a conductive non-reactive electrolyte salt, such as lithium perchlorate, dissolved therein. Optionally, up to 50 weight percent of the solvent can be a second solvent which is an aliphatic or cycloaliphatic carbohydric ether to reduce battery gassing. Additional small amounts of a tertiary nitrogen base can be added to suppress the tendency of the electrolyte system to polymerise.

US-A-4,952,330 discloses a nonaqueous electrolyte for cells, such as Li/FeS_2 cells, comprising a solute, such as LiCF_3SO_3 , dissolved in a mixture of a major amount of dioxolane (e.g. 40-53 volume percent), a minor



amount of propylene carbonate (e.g. 8-18 volume percent) and dimethoxyethane (e.g. 32-45 volume percent). The dioxolane to dimethoxyethane weight ratio for these solutions covers the range of 67 : 33 to 52 : 48.

JP-A-59/173961 discloses organic electrolytes for secondary cells in which the mole ratio of the dioxolane to dimethoxyethane is 2 : 1, corresponding to a weight ratio of 62 : 38.

US-A-3,996,069 discloses a nonaqueous cell utilising a highly active metal anode, such as lithium, a solid cathode selected from the group consisting of FeS_2 , Co_3O_4 , V_2O_5 , Pb_3O_4 , In_2S_3 and CoS_2 , and a liquid organic electrolyte consisting essentially of 3-methyl-2-oxazolidone in combination with a low viscosity co-solvent, such as dioxolane, and a metal salt selected, for example, from MSCN , MCF_3SO_3 , MBF_4 , MClO_4 and $\text{MM}'\text{F}_6$ wherein M' is lithium, sodium or potassium and M is phosphorus, arsenic or antimony.

While the theoretical energy, i.e. the electrical energy potentially available from a selected anode-cathode couple, is relatively easy to calculate, there is a need to choose a nonaqueous electrolyte for such a couple that permits the actual energy produced for an assembled battery to approach the theoretical energy. The problem usually encountered is that it is practically impossible to predict in advance how well, if at all, a nonaqueous electrolyte will function with a selected couple.

Thus, a cell must be considered as a unit having three parts - a cathode, an anode and an electrolyte - and it is to be understood that the parts of one cell are not predictably interchangeable with parts of



another cell to produce an efficient and workable cell.

Many cell systems can function in various environments when they are freshly produced. However, when cell systems are stored for long periods of time at high temperatures, their impedance characteristics can deteriorate, thereby rendering the cell systems unsuitable for consumer applications. Exposing many cell systems to elevated temperatures of 60°C for prolonged periods of time can result in venting of the cell, thereby causing the cell to be unsuitable for many consumer applications.

We have now surprisingly found that, by reducing the amount of the dioxolane-based constituent of the solvent and increasing the amount of the ether-based constituent, electrochemical cells having enhanced qualities can be produced.

Thus, in a first aspect, the present invention provides an organic electrolyte solution for use in a high energy electrochemical cell comprising a solute dissolved in a mixture of a dioxolane-based solvent and an acyclic ether solvent, characterised in that the weight ratio of the dioxolane-based solvent to the acyclic ether solvent is from 1 : 99 to 45 : 55, preferably from 10 : 90 to 40 : 60, and the volume ratio of the dioxolane-based solvent to the acyclic ether solvent is preferably less than 40 : 60.

Alternatively, the present invention provides an organic electrolyte solution for use in an electrochemical cell comprising a solute dissolved in a mixture of a dioxolane-based solvent and an acyclic ether solvent in which the weight ratio of the dioxolane-based solvent to the acyclic ether solvent is from 1 : 99 to 45 : 55 and wherein the volume ratio of



the dioxolane-based solvent to the acyclic ether solvent is less than 40 : 60.

The dioxolane-based solvent is advantageously dioxolane.

The acyclic ether is preferably dimethoxyethane, ethyl glyme, diglyme and triglyme, particularly 1,2-dimethoxyethane.

The organic electrolyte solutions according to the present invention usefully further comprise at least one co-solvent, preferably in an amount less than 25 wt % based on the weight of the solvent of the electrolyte solution. The co-solvent is advantageously selected from 3,5-dimethylisoxazole, 3-methyl-2-oxazolidone, propylene carbonate, ethylene carbonate, butylene carbonate and sulpholane, but is preferably 3,5-dimethylisoxazole.

In a preferred embodiment, there is provided an organic electrolyte solution as defined, and wherein the dioxolane-based solvent is dioxolane, the acyclic ether solvent is 1,2-dimethoxyethane and wherein the weight ratio of the dioxolane to the 1,2-dimethoxyethane is from 10 : 90 to 40 : 60, and further comprising a co-solvent as defined, preferably in an amount less than 25 wt % based on the weight of the solvent of the electrolyte solution, and selected from 3,5-dimethylisoxazole, 3-methyl-2-oxazolidone, propylene carbonate, ethylene carbonate, butylene carbonate and sulpholane, but is preferably 3,5-dimethylisoxazole. More preferably, the co-solvent is 3,5-dimethylisoxazole or 3-methyl-2-oxazolidone.

The solute is advantageously selected from lithium trifluoromethane sulphonate, lithium bistrifluoromethyl-



sulphonyl imide, lithium perchlorate, lithium hexafluoroarsenate, and mixtures thereof, especially lithium trifluoromethane sulphonate.

The present invention further provides an electrochemical cell comprising an anode, a cathode and an organic electrolyte solution of the invention. Such cells, especially high energy cells, are well known in the art, and may be constructed in any suitable manner.

In such cells, the anode is preferably lithium and the cathode is selected from fluorinated carbon, a metal sulphide, a metal oxide, a metal chloride and mixtures thereof, but especially FeS_2 .

The electrolyte solutions of the present invention can be used in an electrochemical cell and stored at high temperatures for extended periods of time without allowing cell impedance to increase to levels which substantially reduce cell performance.

Another advantage of the present invention is that the electrolyte solutions can be employed with an electrochemical cell employing a lithium anode and a cathode such as FeS_2 .

The electrolyte solutions of the present invention are particularly suited to cells employing a lithium anode and an iron sulphide-containing cathode.

Typically, the dioxolane-based solvent will be dioxolane, alkyl-substituted dioxolanes or mixtures thereof. Examples of alkyl-substituted dioxolanes are 4-methyl-1,3-dioxolane and 2,2-dimethyl-1,3-dioxolane. The preferred dioxolane-based solvent for use in the present invention is dioxolane. Typical acyclic ethers suitable for use in the present invention are



dimethoxyethane, ethyl glyme, diglyme and triglyme. The preferred acyclic ether for use in the present invention is 1,2-dimethoxyethane.

For some applications, at least one optional co-solvent may be used, such as one or more of 3,5-dimethylisoxazole, 3-methyl-2-oxazolidone, propylene carbonate, ethylene carbonate, butylene carbonate, sulpholane, tetrahydrofuran, diethyl carbonate, ethylene glycol sulphite, dioxane and dimethyl sulphate. The preferred co-solvents for use in the present invention are 3,5-dimethylisoxazole, 3-methyl-2-oxazolidone and propylene carbonate.

For most applications, addition of the optional co-solvent should be limited to 25 weight percent, or less, based on the total weight of the solvent for the electrolyte, preferably less than 20 weight percent.

It is believed that the low weight ratio of dioxolane-based solvent to the acyclic ether solvent results in a better impedance maintenance of the cells and better performance on high-rate photoflash tests. The present invention is not bound by this theory, however.

It has been observed that the low weight ratio of dioxolane-based solvent to the acyclic ether solvent in the electrolyte solution of the present invention provides good cell impedance, particularly at low frequencies (e.g. 10 Hz) after the cell is stored at 60°C. This is believed to be due to a much better charge transfer resistance than equivalent cells using a higher weight ratio. It is also believed that a low weight ratio of dioxolane-based solvent to the acyclic ether renders the electrolyte solution less sensitive to the effects of polymerisation, which may explain the



better impedance maintenance observed in these cells.

The preferred weight ratio of the dioxolane-based solvent to the acyclic ether solvent is from 10 : 90 to 40 : 60 and the most preferred is 29 : 71. The most preferred electrolyte solution is 29.0 weight percent dioxolane, 70.8 weight percent 1,2-dimethoxyethane and 0.2 weight percent 3,5-dimethylisoxazole, along with 1.0 mole LiCF_3SO_3 per litre of solvent.

Highly active metal anodes suitable for the present invention include lithium, sodium, potassium, calcium, magnesium and their alloys, and metal-intercalated carbon or graphite material, such as lithiated carbon. Of these active metals, lithium is preferred because, in addition to being a ductile, soft metal that can easily be assembled in a cell, it possesses the highest energy-to-weight ratio of the group of suitable anode metals.

Suitable solid cathodes for use in the present invention include: fluorinated carbon, which can be represented by the formula $(\text{CF}_x)_n$ wherein x varies between about 0.5 and about 1.2 and $(\text{C}_2\text{F})_n$ wherein, in both cathodes, n refers to the number of monomer units (which number, it will be appreciated, can vary widely); copper sulphide (CuS); copper oxide (CuO); lead dioxide (PbO_2); iron sulphides (FeS , FeS_2); copper chloride (CuCl_2); silver chloride (AgCl); sulphur; bismuth trioxide (Bi_2O_3); copper bismuth oxide (CuBi_2O_4); cobalt oxides; vanadium pentoxide (V_2O_5); tungsten trioxide (WO_3); molybdenum trioxide (MoO_3); molybdenum disulphide (MoS_2); titanium disulphide (TiS_2); and transition metal polysulphides.

The preferred cathodes for use in the present invention are the iron sulphides alone and in



combination with other cathode materials such as:

$\text{FeS}_2 + \text{CuO};$
 $\text{FeS}_2 + \text{Bi}_2\text{O}_3;$
 $\text{FeS}_2 + \text{Pb}_2\text{Bi}_2\text{O}_5;$
 $\text{FeS}_2 + \text{Pb}_3\text{O}_4;$
 $\text{FeS}_2 + \text{CuO} + \text{Bi}_2\text{O}_3;$
 $\text{FeS}_2 + \text{CuO} + \text{Pb}_3\text{O}_4;$
 $\text{FeS}_2 + \text{CuO} + \text{CoS}_2;$
 $\text{FeS}_2 + \text{MnO}_2;$ and
 $\text{FeS}_2 + \text{CoS}_2.$

The ionisable solute for use in the present invention may be a simple salt, such as LiCF_3SO_3 or lithium bistrifluoromethylsulphonyl imide ($\text{Li}(\text{CF}_3\text{SO}_2)_2\text{N}$), for example, or a double salt or mixtures thereof which will produce an ionically conductive solution when dissolved in the solvent. Suitable solutes are complexes of inorganic or organic Lewis acids and inorganic ionisable salts.

One of the requirements for utility is that the salts, whether simple or complex, be compatible with the solvent(s) being employed and that they yield a solution which is sufficiently ionically conductive, generally at least about $10^{-4} \text{ ohm}^{-1} \text{ cm}^{-1}$. Generally, a concentration of at least about 0.5 M would be sufficient for most cell applications.

Typical suitable Lewis acids include aluminium fluoride, aluminium bromide, aluminium chloride, antimony pentachloride, zirconium tetrachloride, phosphorus pentachloride, phosphorus pentafluoride, boron fluoride, boron chloride, boron bromide and arsenic pentafluoride.

Ionisable salts useful in combination with the Lewis acids include lithium fluoride, lithium chloride,



lithium bromide, lithium sulphide, sodium fluoride, sodium chloride, sodium bromide, potassium fluoride, potassium chloride and potassium bromide.

The ionisable solute for use in conjunction with an iron sulphide-containing cathode would suitably be lithium trifluoromethane sulphonate (LiCF_3SO_3), lithium bistrifluoromethylsulphonyl imide ($\text{Li}(\text{CF}_3\text{SO}_2)_2\text{N}$), lithium perchlorate (LiClO_4), lithium hexafluoroarsenate (LiAsF_6) or mixtures thereof, lithium trifluoromethane sulphonate being the most preferred. Suitable double salts for various cell applications include lithium tetrafluoroborate (LiBF_4), lithium hexafluorophosphate (LiPF_6) and potassium hexafluoroarsenate (KAsF_6).

EXAMPLE

Several cells were produced, each containing an anode of 0.95 g of lithium; a cathode of 4.1 g of a mix containing 91 wt % FeS_2 , 2.25 wt % acetylene black, 4.75 wt % graphite and 2 wt % metallic zinc; and 2 g of an electrolyte as shown in Table 1.



TABLE 1ELECTROLYTE SOLUTION

LOT NO.	DIOX (wt/%)	DME (wt/%)	3Me2Ox (wt/%)	DMI (wt/%)	LiCF ₃ SO ₃ (Moles/ litre of solvent)
A	29.0	70.8	0	0.2	1.5
B*	55.0	44.8	0	0.2	1.5
C*	78.5	21.3	0	0.2	1.5
D	25.4	61.9	12.5	0.2	1.0
E*	69.6	18.9	11.4	0.2	1.0

In the above Table, DIOX is dioxolane, DME is 1,2-dimethoxyethane, DMI is 3,5-dimethylisoxazole, 3Me2Ox is 3-methyl-2-oxazolidone, and * indicates a comparative Lot.

Samples of the cells (5 cells per lot) were stored for 12 weeks at 60°C. After storage the cells were checked for 1 kHz impedance, open circuit voltage (OCV), closed circuit voltage (CCV; 0.5 second on 3.9-ohm load) and flash amperage. The flash amperage test consisted of a 200-millisecond closed circuit voltage on a 0.01-ohm load. Furthermore, two simulated photoflash tests per lot were carried out. Each test involved measuring the recycle time of a pair of cells in a Pentax PC303 35 mm camera with a built-in flash unit. The recycle time is the time for the "ready light" to come back on after the first flash. This time should be as short as possible.

The data obtained are shown in Table 2.



TABLE 2

Lot No.	1 kHz	OCV (V)	CCV (V)	Flash	Average
	Impedance Ω			Amperage (A)	Recycle Time (s)
A	0.48	1.84	1.60	4.26	6.6
B	0.59	1.84	1.54	2.79	8.6
C	0.77	1.83	1.45	2.45	8.6
D	0.59	1.83	1.37	3.92	7.8
E	0.57	1.84	1.41	3.89	10.1

The data show an unexpected advantage for low dioxolane : 1,2-dimethoxyethane weight ratio electrolytes (Samples A and D). Specifically, Lot A gave much better cell impedance, closed circuit voltage, flash amperage and recycle times than Lot B or Lot C after 60°C storage. Lot D also gave much better recycle times than Lot E after 60°C storage.

Cells containing no dioxolane (i.e., only 1,2-dimethoxyethane and 0.2% 3,5-dimethylisoxazole) vent during 60°C storage, thereby demonstrating the need for the dioxolane-based constituent.



CLAIMS:

1. An organic electrolyte solution for use in a high energy electrochemical cell comprising a solute dissolved in a mixture of a dioxolane-based solvent and an acyclic ether solvent, characterised in that the weight ratio of the dioxolane-based solvent to the acyclic ether solvent is from 1 : 99 to 45 : 55 and the volume ratio of the dioxolane-based solvent to the acyclic ether solvent is preferably less than 40 : 60.
2. A solution according to claim 1, wherein the weight ratio of the dioxolane-based solvent to acyclic ether solvent is from 10 : 90 to 40 : 60, preferably 29 : 71.
3. A solution according to claim 1 or 2, wherein the dioxolane-based solvent is dioxolane.
4. A solution according to any preceding claim, wherein the acyclic ether is selected from dimethoxyethane, ethyl glyme, diglyme and triglyme, preferably 1,2-dimethoxyethane.
5. A solution according to any preceding claim, wherein at least one co-solvent is included in the electrolyte solution.
6. A solution according to claim 5, wherein the co-solvent is present in an amount less than 25 wt % based on the weight of the solvent of the electrolyte solution.
7. A solution according to claim 5 or 6, wherein the co-solvent is selected from 3,5-dimethylisoxazole, 3-methyl-2-oxazolidone, propylene carbonate, ethylene carbonate, butylene carbonate and/or sulpholane, preferably 3,5-dimethylisoxazole.





8. A solution according to any preceding claim, comprising 29.0 weight percent dioxolane, 70.8 weight percent 1,2-dimethoxyethane and 0.2 weight percent 3,5-dimethylisoxazole, along with 1.0 mole LiCF_3SO_3 per litre of solvent.

9. A solution according to any preceding claim, wherein the solute is selected from lithium trifluoromethane sulphonate, lithium bistrifluoromethylsulphonyl imide, lithium perchlorate, lithium hexafluoroarsenate, and mixtures thereof, preferably lithium trifluoromethane sulphonate.

10. An, preferably high energy, electrochemical cell comprising an anode, a cathode and an organic electrolyte solution according to any preceding claim.

11. An electrochemical cell according to claim 10, wherein the anode is lithium and the cathode is selected from fluorinated carbon, a metal sulphide, a metal oxide, a metal chloride and mixtures thereof, preferably FeS_2 .

