

PATENT SPECIFICATION

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 36Y 37X 386 38Y 43X 43Y 579 589 58X 595 596 597
 602 61X 631 634 635 638 63X 63Y 65X 661 662 665
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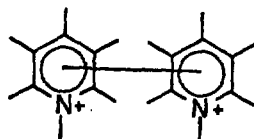


(54) PREPARATION OF BIPYRIDILIUM COMPOUNDS

(71) We, IMPERIAL CHEMICAL INDUSTRIES LIMITED, Imperial Chemical House, Millbank, London SW1P 3JF, a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method for the preparation of compounds having a bipyridilium nucleus and to the compounds so obtained.

Compounds comprising the structure:

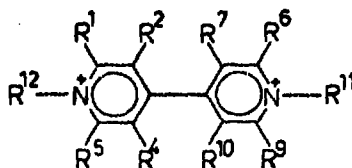


2X⁻

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are known and examples have been disclosed in our British Patent Specification number 1,310,812.

The present invention provides a method for the preparation of a bipyridilium compound having the formula;

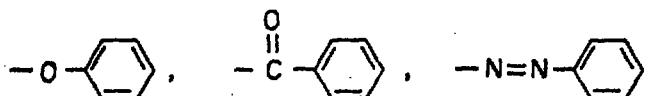


2X⁻

II

in which R¹ to R¹² and X⁻ are as hereinafter defined, which method comprises the step of contacting an N,N'-bis(2,4-dinitrophenyl)4,4'-pyridilium salt with a primary aryl amine, said aryl grouping being that which it is desired to introduce into the R¹¹ or R¹² position in the bipyridilium compound, in an inert polar medium, the molar ratio of the amine to salt being at least 4 to 1.

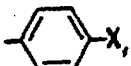
R¹ to R¹⁰ are H, F, Cl or organic substituents, preferably at least one of R¹ and R³ and of R⁶ and R¹⁰ are H, and R¹¹ and R¹² are organic radicals at least one being a phenyl group substituted with an alkyl group having from 2 to 12 carbon atoms, —COOR¹³ (where R¹³ is an alkyl group having 1 to 10 carbon atoms, an aryl group or hydrogen), an amide group, hydroxyl,

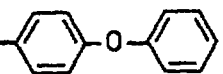
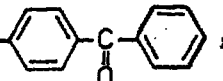


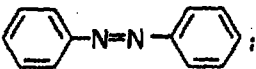
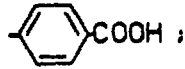
halogen, or being a polycyclic aromatic group e.g. naphthyl, which may optionally bear substituents, particularly electron withdrawing groups para to the point of attachment of the aromatic nucleus to the N of the heterocyclic nucleus; X^- is an anion derived from an acid, preferably a strong mineral acid having a pK_a less than 2.5, or an organic acid.

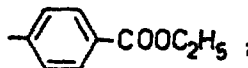
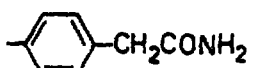
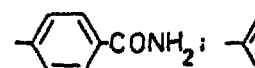
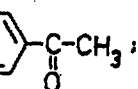
As specific examples of groups R^1 to R^{10} , we mention alkyl, particularly C_1 to C_{12} , (preferably C_1 to C_3), aryl, aralkyl, alkaryl and oxyhydrocarbyl groups, as indicated in the above mentioned British Patent Specification. Bulky groups which interfere sterically with the synthesis or use of such compounds should preferably be avoided, and readily reducible groups, e.g. NO_2 , should preferably be absent.

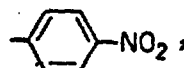
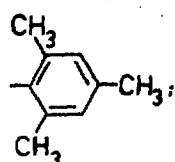
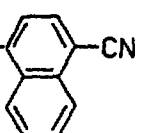
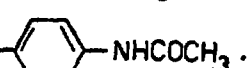
As specific examples of Groups R^{11} and R^{12} we may mention:

phenyl; 

where $X = F, Cl, Br$ or I ; ; ; 

where $R = CH_3, -C_2H_5$, or $n-C_4H_9$; ; 

; ; ; 

; ;  and 

Inorganic anions include F^- , Cl^- , Br^- , SO_4^{2-} , lower alkyl (C_1 to C_3) sulphate chlorate, perchlorate, BF_4^- , SiF_6^{2-} , NO_3^- , sulphonates.

Organic anions include: acetate, citrate, tartrate, formate, maleate, oxalate and other water soluble anions of mono-, di- and tri-carboxylic acids, particularly those bearing hydroxylic groups.

It will be appreciated that the compounds listed above exemplify, but not exhaustively, the compounds which may be prepared according to the method of the invention.

Preferred salts employed according to the invention are halides, particularly fluorides and chlorides, and alkyl sulphates, particularly lower alkyl (C_1 to C_3) sulphates, for example methyl and ethyl sulphates.

Yield of the product is influenced *inter alia* by the mole ratio of the amine to DNP. At least 4 moles of amine are used per mole of DNP salt, the more preferred ratio being 5 to 6 moles to one of the DNP salt. The upper limit is not critical but conveniently it should not exceed about 10:1.

The medium employed should be inert, i.e. so that it does not react chemically with the reactants or products. The medium employed is one capable of dissolving an ionic material. It should also provide a high (e.g. >75% w/w) degree (although not necessarily complete) of solubility of the amine. The medium is preferably water, optionally mixed with a water miscible polar solvent (having a high dielectric constant, e.g. greater than 15). The medium employed should not tend to bring about separation of ionic and non-ionic reactants, which results in uptake of a substantial proportion of the amine in the non-ionic phase. Examples of water miscible polar solvents which may be employed are alcohols (e.g. ethanol, methanol, propanol), dimethyl formamide and acetonitrile.

The reaction is conveniently carried out at a temperature at which reflux of the medium occurs, and conveniently not higher than about $160^\circ C$; preferably the reaction is carried out at a temperature not lower than about $50^\circ C$. It should be noted that not all the amine need be in solution; part may be in suspension for a time before it reacts, dissolution proceeding as the reaction proceeds. Reaction under an inert atmosphere, for example nitrogen, is preferred but not essential. Preferably the ionic reactant is completely dissolved in the medium.

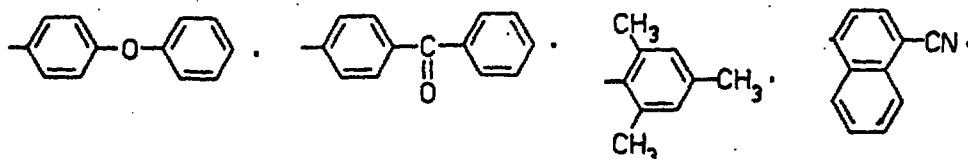
The reaction time is usually of the order of $\frac{1}{2}$ to 4 hours. At the end of the reaction time the solution is cooled and some crude product may crystallise out.

Remaining product can be extracted with a water immiscible organic solvent, e.g. chloroform or toluene, and still more product recovered by evaporation of the aqueous solution. The resulting solid material contains the product, starting material, intermediates and 2,4-dinitroaniline.

Digestion of the solids in hot alcohol, preferably in hot ethanol, dissolves the unreacted amine and non-ionic products and assists in converting intermediates to the product, which usually is not very soluble in ethanol.

The product can be recrystallised from glacial acetic acid. Crystalline product is obtained containing acetic acid, which usually may be removed by vacuum drying at a temperature of at least 80°C. Further purification conveniently comprises one or more of the steps of dissolving the solid in hot water, decolourising with activated charcoal and precipitation from concentrated solution at elevated temperature usually about 60°C by addition to 3 to 5 times its volume of acetone, isobutanol or acetonitrile.

Certain of the compounds described above are novel per se, including compounds in which R¹¹ or R¹² is:—



The ring(s) may carry one or more substituents which, when present, preferably are lower alkyl (C₁ to C₃) groups, more preferably C₁ to C₃.

In particular, the weak hydroxy acid salts (mono, di or tricarboxy) of all of the aforementioned bipyridilium compounds are novel, specifically the citrates and tartrates.

The compounds of the invention may find application for example in devices in which use is made of the property of the compound of reacting reversibly to passage of an electric current through a solution of the compound. This phenomenon depends upon the fact that the di-cation in a suitable solvent and particularly in aqueous solution, may be electrochemically reduced to a highly coloured water-insoluble, or only slightly water-soluble, radical cation. Formation of the radical cation occurs at the cathode and the radical cation tends to remain in association therewith, usually deposited upon the electrode as a solid layer. The deposit of the radical cation may be removed from the cathode by oxidation, either chemical or by reversal of polarity of the electrode, when the cation radical is reoxidised to the soluble and (usually) much less coloured di-cationic species.

In particular the compounds may find application in electrochromic display devices and systems as described in our earlier US Patent Specification No. 3,712,709 and in British Patent Specifications Nos. 1,302,000, 1,407,133 and 1,490,971.

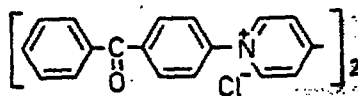
In use in an electrochromic device as described, the electrodes employed are chemically inert to the electrolyte with which they are in contact, and may be of any suitable material, e.g. metals such as gold, and platinum, electrically conducting glasses or glass or other support material having an electrically conductive inert surface, for example a thin metallic film. A small potential difference is usually adequate to effect reduction; we prefer to use voltages of the order of 0.5—3v.

We make no claim to the use the process of the invention in the production of p-cyanophenyl bipyridilium salts.

The invention is illustrated by the following Examples, in which all parts are by weight.

Example 1.

Preparation of



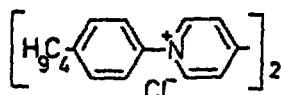
To a refluxing solution containing 4-amino benzophenone (98.5 parts) in water (500 parts) and dimethylformamide (300 parts) was added a hot solution (80–90°C) containing N,N'-bis(2,4-dinitrophenyl)-4,4'-bipyridylium dichloride (56.1 parts) in water (400 parts) over a period of 20 minutes, whilst the reaction mixture was stirred vigorously. Reflux conditions were maintained for a further one hour period and then the reaction mixture was cooled to ambient temperature. The reaction mixture was poured into stirred acetone (4000 parts) when a fawn-brown coloured solid precipitated. The precipitate was collected by filtration, washed thoroughly on a filter with boiling dry acetone and dried under vacuum at 60°C. Yield 48 parts, % yield = 81.5%.

The crude solid was dissolved in hot water (50 parts) and treated with activated carbon, filtered to remove carbon, and the filtrate evaporated slowly to dryness under vacuum. A pale yellow crystalline solid was obtained as a dihydrate which decomposed at 270°C. Yield = 74.5%.

Calculated for $C_{36}H_{30}N_2O_2Cl_2$ = C, 69.2; H, 4.8; N, 4.48;
O, 10.23; Cl, 11.27%
Found: C, 69.45; H, 5.07; N, 4.48;
O, 10.37; Cl, 11.63%.

Example 2.

Preparation of N,N'-Bis (p-n-butylphenyl)4,4'-bipyridilium dichloride



A hot solution of DNP (28 parts) in water (75 parts) was added dropwise to a refluxing solution of p-n-butyl aniline (37.5 parts) in water (25 parts) and dimethylformamide (50 parts) over a period of 20 minutes. Thereafter, reflux conditions were maintained for a further period of 2 hours. On cooling the black-purple solid deposited was removed by filtration and the aqueous filtrate evaporated to dryness by rotary evaporation under vacuum to yield a further quantity of solid product.

The two solids were combined and digested in boiling ethanol (150 parts) and the warm mixture poured into stirred acetone (500 parts) when a fawn coloured solid precipitated. The solid was removed by filtration, washed with acetone until washings were almost colourless, then recrystallised from glacial acetic acid after treatment with activated carbon. The yellow solid which crystallised contained acetic acid of crystallisation. The crude product was dissolved in a minimum volume of boiling water, again treated with activated carbon to produce an almost colourless aqueous solution which was poured slowly into an excess of stirred acetone.

An almost white microcrystalline solid precipitated which was removed by filtration, washed with dry acetone, followed by an ether washing and finally dried under vacuum at 60°C for 4 hours when 23 parts of a dihydrated salt were obtained. % yield = 87%.

Calculated for $C_{30}H_{38}N_2Cl_2O_2$ = C, 68.0; H, 7.2; N, 5.3;
Cl, 13.4; O, 6.1%
Found: C, 67.7; H, 7.5; N, 5.7;
Cl, 13.4; O, 5.6%

Examples 3 to 21.

The process of Example 1 was repeated generally as described, except that the amine referred to therein was substituted by the amines listed in Table 1. Proportions of reactants — amine, DNP and solvents — are indicated also, together with the product in each case. Ph represents phenyl and, where they are present, substituents thereon are, in all the Examples, in the para position.

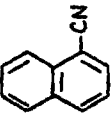
Table 2 shows the colours of the cation radicals derived from the-di-quaternary compounds.

TABLE I

DNP Reaction With Primary Aromatic Amines

Example No.	Amine	Parts Amine by weight	Parts DNP by weight	Solvents & Parts by weight	R ¹¹ -R ¹²
3	Aniline	232.5	280.5	DMF, 750 H ₂ O, 1100	-Ph
4	p-Fluoro aniline	227	280.5	DMF, 100 H ₂ O, 1800	-Ph-F
5	p-Chloro aniline	318.8	280.5	DMF, 150 H ₂ O, 225	-Ph-Cl
6	p-Bromo aniline	430	280.5	DMF, 250 H ₂ O, 1300	-Ph-Br
7	p-Iodo aniline	547.5	280.5	DMF, 250 H ₂ O, 850	-Ph-I
8	p-Methyl aniline	267.5	280.5	DMF, 100 H ₂ O, 2000	-Ph-CH ₃
9	p-Ethyl aniline	302.5	280.5	H ₂ O, 2000	-Ph-C ₂ H ₅
10	p-n-Butyl aniline	375	280.5	DMF, 500 H ₂ O, 1000	-Ph-C ₄ H ₉
11	p-Amino benzoic acid	342.5	280.5	DMF, 200 H ₂ O, 1150	-Ph-COOH
12	p-Amino ethyl benzoate	412.5	280.5	DMF, 1250 H ₂ O, 1250	-Ph-COOC ₂ H ₅
13	p-Amino benzamide	340	280.5	DMF, 200 H ₂ O, 1200	-Ph-CONH ₂
14	p-Nitro aniline	345	280.5	DMF, 200 H ₂ O, 1700	-Ph-NO ₂
15	2,4,6-Trimethyl aniline	337.5	280.5	H ₂ O, 2000	-Ph(CH ₃) ₃
16	4-Amino benzophenone	985	561	DMF, 3000 H ₂ O, 9000	-Ph-CO-Ph

TABLE 1 (Continued)

Example No.	Amine	Parts Amine by weight	Parts DNP by weight	Solvents & Parts by weight	R ¹¹ =R ¹²
17	4-Amino acetophenone	135.2	112.2	DMF, 500 H ₂ O, 1500	-Ph-CO-CH ₃
18	p-Phenoxy aniline	185	112.2	DMF, 500 H ₂ O, 1500	-Ph-O-Ph
19	1-Amino 4-cyanonaphthalene	420	280.5	DMF, 500 H ₂ O, 1500	
20	p-Azophenyl aniline	492.5	280.5	DMF, 400 H ₂ O, 800	-Ph-N=N-Ph
21	p-Amino acetanilide	375	280.5	DMF, 250 H ₂ O, 1000	-Ph-NHCOCH ₃

20 ml samples of aqueous solutions containing 0.01 moles/litre of the above quaternary salts of 4,4'-bipyridyl and 0.1 mole/litre of tetraethylammonium chloride (included to increase electrical conductivity of the solution) were tested for electrochemical generation of their respective cation radicals. The voltage at which the radical cations formed and their colour was recorded for both Au and Pt electrodes.

TABLE 2

Example No.	Voltage V		Colour of Radical	
	Gold	Platinum	Gold	Platinum
3	1.5	1.5	very dark green	golden-brown
4	1.4	1.3	deep maroon almost black	deep maroon
5	1.2	1.5	dark green	green
6	1.0	1.0	very dark green	dark green
7	N.A.	N.A.	N.A.	N.A.
8	1.4	1.2	black	red-black
9	1.0	1.0	very dark red almost black	red-brown
10	2.0	1.5	very dark green	almost black
11	N.A.	N.A.	dark green	
12	1.3	1.3	green	green
13	N.A.	N.A.	dark green	
14	2.0	1.8	green	green
15	1.8	1.8	dark green	golden-orange
16	1.0	1.0	almost black	almost black
17	1.0	1.3	dark green	dark green
18	1.0	1.0	almost black	black
19	N.A.	N.A.	dark green	—
20	G	—	—	—
21	2.0	2.0	appears black in red salt	almost black

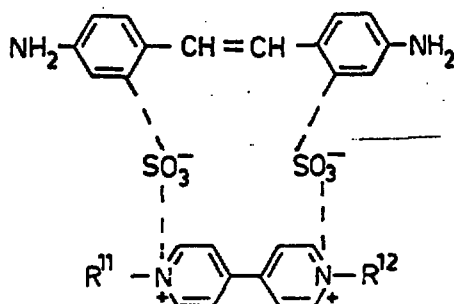
N.A.—not available

Preparation of compounds having anions other than that indicated in the preceding examples may conveniently be effected for example by ion exchange as follows:—

(1) the use of anionic exchange resins e.g. Deacidite (RTM) FFIP (supplied by Permutit Company in chloride form) which may be exchanged with an appropriate anion e.g. fluoride. The resin bearing the desired anion may then be used to exchange the bipyridylum salt (usually in chloride form) anion for that on the resin.

(2) Use of amsonic acid* (as diammonium salt). The water soluble ammonium amsonate may be caused to react with the bipyridylum salt in aqueous solution to form the bipyridylum amsonate salt as a high insoluble salt e.g.

* 4,4'-Diamino-stilbene-2,2'-disulphonic acid

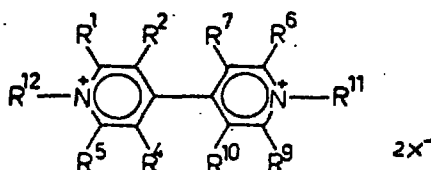


This salt may be reacted with mineral acids or carboxylic acids which are stronger acids than amsonic acid to precipitate amsonic acid in aqueous solutions in which the bipyridylium salt of that acid is soluble.

It has been mentioned above that the novel compounds of the invention, or compounds obtained by the process of the invention, may find application in devices in which colour change of an electrode is effected by passing a current through a solution of the compound, and the present invention includes devices comprising a solution of a novel compound as hereinbefore described, or a compound obtained by the process as hereinbefore described, together with two or more inert electrodes and means for connecting said electrodes to a source of electricity whereby an electric current may be caused to flow through the said solution to effect a colour change by reduction of the cation. Advantageously, the solution comprises, as mentioned in one or more of the aforementioned patents and applications, an auxiliary redox system whereby electrochemical oxidation of the reduced coloured species is facilitated.

WHAT WE CLAIM IS:—

1. A method for the preparation of a bipyridilium compound having the formula



in which R¹ to R¹² and X⁻ are as hereinbefore defined, which method comprises the step of contacting an N,N'-bis(2,4-dinitrophenyl)4,4'-bipyridilium salt with a primary aryl amine, said aryl grouping being that which it is desired to introduce into the R¹¹ or R¹² position in the bipyridilium compound, in an inert polar medium, the molar ratio of the amine to salt being at least 4 to 1.

2. A method according to claim 1 in which R¹¹ and R¹² are the same.

3. A method according to claim 1 or 2 in which X⁻ is an anion derived from a mineral acid having a pK_a less than 2.5.

4. A method according to claim 1, 2 or 3 in which the salt is a halide or an alkyl sulphate.

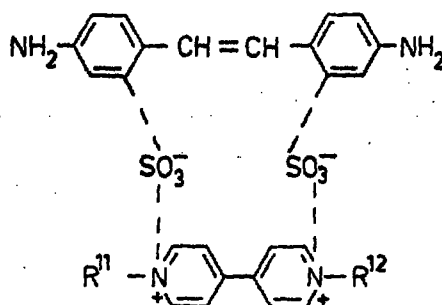
5. A method according to any one of the preceding claims in which the medium comprises water together with another inert polar liquid medium.

6. A method according to any one of the preceding claims in which the reaction is carried out at the reflux temperature of the medium.

7. A method according to claim 1 and substantially as described in any one of the examples.

8. A method according to claim 1 and substantially as hereinbefore described.

9. A compound prepared by the method of any one of the preceding claims comprising a bipyridilium nucleus substituted in the R¹¹ and/or R¹² position with the grouping

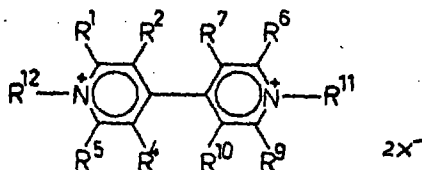


This salt may be reacted with mineral acids or carboxylic acids which are stronger acids than amsonic acid to precipitate amsonic acid in aqueous solutions in which the bipyridilium salt of that acid is soluble.

It has been mentioned above that the novel compounds of the invention, or compounds obtained by the process of the invention, may find application in devices in which colour change of an electrode is effected by passing a current through a solution of the compound, and the present invention includes devices comprising a solution of a novel compound as hereinbefore described, or a compound obtained by the process as hereinbefore described, together with two or more inert electrodes and means for connecting said electrodes to a source of electricity whereby an electric current may be caused to flow through the said solution to effect a colour change by reduction of the cation. Advantageously, the solution comprises, as mentioned in one or more of the aforementioned patents and applications, an auxiliary redox system whereby electrochemical oxidation of the reduced coloured species is facilitated.

WHAT WE CLAIM IS:—

1. A method for the preparation of a bipyridilium compound having the formula



in which R¹ to R¹² and X⁻ are as hereinbefore defined, which method comprises the step of contacting an N,N'-bis(2,4-dinitrophenyl)4,4'-bipyridilium salt with a primary aryl amine, said aryl grouping being that which it is desired to introduce into the R¹¹ or R¹² position in the bipyridilium compound, in an inert polar medium, the molar ratio of the amine to salt being at least 4 to 1.

2. A method according to claim 1 in which R¹¹ and R¹² are the same.

3. A method according to claim 1 or 2 in which X⁻ is an anion derived from a mineral acid having a pKa less than 2.5.

4. A method according to claim 1, 2 or 3 in which the salt is a halide or an alkyl sulphate.

5. A method according to any one of the preceding claims in which the medium comprises water together with another inert polar liquid medium.

6. A method according to any one of the preceding claims in which the reaction is carried out at the reflux temperature of the medium.

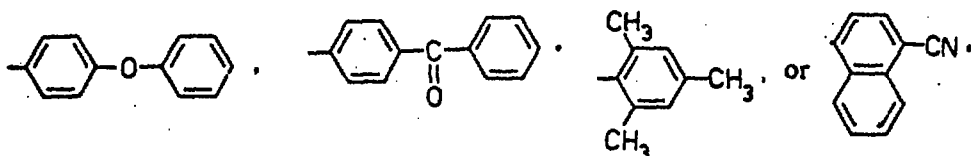
7. A method according to claim 1 and substantially as described in any one of the examples.

8. A method according to claim 1 and substantially as hereinbefore described.

9. A compound prepared by the method of any one of the preceding claims comprising a bipyridilium nucleus substituted in the R¹¹ and/or R¹² position with the grouping



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10. A bipyridilium compound prepared by the method of any one of claims 1 to 8 which is the salt of a weak hydroxy acid.
11. A compound according to claim 10 which is the salt of tartaric or citric acid.

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B. J. BATE,
Agent for the Applicants.

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