

CLAIMS:

1. A nonaqueous electrolyte solution for a lithium battery, which solution comprises
 - i) a liquid electrolyte medium;
 - ii) a lithium-containing salt;
 - iii) 4-bromomethyl-1,3-dioxolan-2-one; and
 - iv) at least one electrochemical additive selected from:
 - a) unsaturated cyclic carbonates containing three to about six carbon atoms,
 - b) fluorine-containing saturated cyclic carbonates containing three to about five carbon atoms and one to about four fluorine atoms,
 - c) tris(trihydrocarbylsilyl) phosphites containing three to about nine carbon atoms,
 - d) trihydrocarbyl phosphates containing three to about twelve carbon atoms,
 - e) cyclic sultones containing three to about eight carbon atoms,
 - f) saturated cyclic hydrocarbyl sulfites having a 5-membered or 6-membered ring and containing two to about six carbon atoms,
 - g) saturated cyclic hydrocarbyl sulfates having a 5-membered or 6-membered ring and containing two to about six carbon atoms,
 - h) cyclic dioxadithio polyoxide compounds having a 6-membered, 7-membered, or 8-membered ring and containing two to about six carbon atoms,
 - i) another lithium-containing salt, and
 - j) mixtures of any two or more of the foregoing.
2. A solution as in Claim 1 wherein the electrochemical additive is selected from:
 - a) unsaturated cyclic carbonates containing three to about four carbon atoms,
 - b) fluorine-containing saturated cyclic carbonates containing three to about four carbon atoms and one to about two fluorine atoms,
 - c) tris(trihydrocarbylsilyl) phosphites containing three to about six carbon atoms,
 - d) trihydrocarbyl phosphates containing three to about nine carbon atoms,
 - e) cyclic sultones containing three to about four carbon atoms,
 - f) saturated cyclic hydrocarbyl sulfites having a 5-membered ring and containing two to about four carbon atoms,
 - g) saturated cyclic hydrocarbyl sulfates having a 5-membered ring and containing two to about four carbon atoms,

- h) cyclic dioxadithio polyoxide compounds having a 6-membered or 7-membered ring and containing two to about four carbon atoms,
 - i) another lithium-containing salt, and
 - j) mixtures of any two or more of the foregoing.
3. A solution as in Claim 1 or 2 wherein the electrochemical additive is selected from:
- a) an unsaturated cyclic carbonate in an amount of about 0.5 wt% to about 12 wt%, relative to the total weight of the nonaqueous electrolyte solution,
 - b) a fluorine-containing saturated cyclic carbonate in an amount of about 0.5 wt% to about 8 wt%, relative to the total weight of the nonaqueous electrolyte solution,
 - c) a tris(trihydrocarbylsilyl) phosphite in an amount of about 0.1 wt% to about 5 wt%, relative to the total weight of the nonaqueous electrolyte solution,
 - d) a trihydrocarbyl phosphate in an amount of about 0.5 wt% to about 5 wt%, relative to the total weight of the nonaqueous electrolyte solution,
 - e) a cyclic sultone in an amount of about 0.25 wt% to about 5 wt%, relative to the total weight of the nonaqueous electrolyte solution,
 - f) a cyclic sultone in an amount of about 1.5 wt% to about 12 wt%, relative to the total weight of the nonaqueous electrolyte solution,
 - g) a saturated cyclic hydrocarbyl sulfite in an amount of about 0.5 wt% to about 5 wt%, relative to the total weight of the nonaqueous electrolyte solution,
 - h) a saturated cyclic hydrocarbyl sulfate in an amount of about 0.25 wt% to about 5 wt%, relative to the total weight of the nonaqueous electrolyte solution,
 - i) a cyclic dioxadithio polyoxide compound in an amount of about 0.5 wt% to about 5 wt%, relative to the total weight of the nonaqueous electrolyte solution,
 - j) another lithium-containing salt in an amount of about 0.5 wt% to about 5 wt%, relative to the total weight of the nonaqueous electrolyte solution, and
 - k) mixtures of any two or more of the foregoing.
4. A solution as in any of Claims 1-3 wherein the electrochemical additive is a saturated cyclic hydrocarbyl sulfate, a cyclic sultone, or another lithium-containing salt.
5. A solution as in Claim 1 wherein the electrochemical additive is a saturated cyclic hydrocarbyl sulfate in an amount of about 1 wt% to about 4 wt%, a cyclic sultone in an amount of about 0.5 wt% to about 4 wt%, a cyclic sultone in an amount of about 1.5 wt% to about 12 wt%, a tris(trihydrocarbylsilyl) phosphite in an amount of about 0.2 wt% to

about 3 wt%, or another lithium-containing salt in an amount of about 1 wt% to about 4 wt%, each relative to the total weight of the nonaqueous electrolyte solution.

6. A solution as in Claim 1 or Claim 5 wherein the electrochemical additive is 1,3,2-dioxathiolane 2,2-dioxide, 1,3-propene sultone, 1,3-propane sultone, tris(trimethylsilyl)phosphite, lithium di(fluoro)(oxalato)borate, or lithium bis(oxalato)borate.

7. A solution as in Claim 5 or Claim 6 wherein each electrochemical additive is not used with other electrochemical additives.

8. A solution as in any of Claims 1-3 wherein the electrochemical additive is a mixture of an unsaturated cyclic carbonate and a saturated cyclic hydrocarbyl sulfite, or a mixture of a cyclic sultone, a tris(trihydrocarbylsilyl) phosphite, and a cyclic dioxadithio polyoxide.

9. A solution as Claim 8 wherein the combined amount of the electrochemical additives in each mixture is about 0.25 wt% to about 5 wt%, relative to the total weight of the nonaqueous electrolyte solution.

10. A solution as in any of Claims 1-9 wherein the 4-bromomethyl-1,3-dioxolan-2-one is in an amount of about 10 wt% or more bromine relative to the total weight of the solution.

11. A solution as in any of Claims 1-9 wherein the liquid electrolyte medium is ethylene carbonate, ethyl methyl carbonate, or a mixture thereof, and/or wherein the lithium-containing salt is lithium hexafluorophosphate.

12. A solution as in Claim 1 wherein the nonaqueous electrolyte solution further comprises vinylene carbonate in an amount of about 8 wt% to about 11 wt%, relative to the total weight of the nonaqueous electrolyte solution.

13. A nonaqueous lithium battery comprising a positive electrode, a negative electrode, and a nonaqueous electrolyte solution as in any of Claims 1-12.

14. A nonaqueous electrolyte solution for a lithium battery, which solution comprises

- i) a liquid electrolyte medium;
- ii) a lithium-containing salt;
- iii) 4-bromomethyl-1,3-dioxolan-2-one; and

iv) at least one electrochemical additive selected from vinylene carbonate, 4-fluoro-ethylene carbonate, tris(trimethylsilyl)phosphite, triallyl phosphate, 1,3-propane sultone, 1,3-propene sultone, 1,3,2-dioxathiolane 2-oxide, 1,3,2-dioxathiolane 2,2-dioxide, 1,5,2,4-dioxadithiane 2,2,4,4-tetroxide, lithium di(fluoro)(oxalato)borate, lithium bis(oxalato)borate, and mixtures of any two or more of these.

15. A solution as in Claim 14 wherein the electrochemical additive is selected from:
- vinylene carbonate in an amount of about 0.5 wt% to about 3 wt%, relative to the total weight of the nonaqueous electrolyte solution;
 - vinylene carbonate in an amount of about 8 wt% to about 11 wt%, relative to the total weight of the nonaqueous electrolyte solution;
 - 4-fluoro-ethylene carbonate in an amount of about 1.5 wt% to about 5 wt%, relative to the total weight of the nonaqueous electrolyte solution;
 - tris(trimethylsilyl) phosphite in an amount of about 0.2 wt% to about 3 wt%, relative to the total weight of the nonaqueous electrolyte solution;
 - triallyl phosphate in an amount of about 1 wt% to about 5 wt%, relative to the total weight of the nonaqueous electrolyte solution;
 - 1,3-propane sultone or 1,3-propene sultone in an amount of about 0.5 wt% to about 4 wt%, relative to the total weight of the nonaqueous electrolyte solution;
 - 1,3-propane sultone in an amount of about 1.5 wt% to about 12 wt%, relative to the total weight of the nonaqueous electrolyte solution;
 - 1,3,2-dioxathiolane 2-oxide in an amount of about 1 wt% to about 4 wt%, relative to the total weight of the nonaqueous electrolyte solution;
 - 1,3,2-dioxathiolane 2,2-dioxide in an amount of about 1 wt% to about 4 wt%, relative to the total weight of the nonaqueous electrolyte solution;
 - 1,5,2,4-dioxadithiane 2,2,4,4-tetroxide in an amount of about 1 wt% to about 4 wt%, relative to the total weight of the nonaqueous electrolyte solution;
 - lithium di(fluoro)(oxalato)borate in an amount of about 1 wt% to about 4 wt%, relative to the total weight of the nonaqueous electrolyte solution;
 - lithium bis(oxalato)borate in an amount of about 1 wt% to about 4 wt%, relative to the total weight of the nonaqueous electrolyte solution; and
 - mixtures of any two or more of these.

16. A solution as in Claim 14 or 15 wherein the electrochemical additive is selected from 1,3-propane sultone, 1,3-propene sultone, 1,3,2-dioxathiolane 2,2-dioxide, tris(trimethylsilyl)phosphite, lithium di(fluoro)(oxalato)borate, and lithium bis(oxalato)borate.

17. A solution as in Claim 14 wherein the electrochemical additive selected from 1,3-propane sultone in an amount of about 0.5 wt% to about 4 wt%, 1,3-propene sultone in an amount of about 1.5 wt% to about 12 wt%, 1,3,2-dioxathiolane 2,2-dioxide, in an amount of about 1 wt% to about 4 wt%, lithium di(fluoro)(oxalato)borate in an amount of about 1 wt% to about 4 wt%, and lithium bis(oxalato)borate in an amount of about 1 wt% to about 4 wt%, each relative to the total weight of the nonaqueous electrolyte solution.

18. A solution as in Claim 16 or 17 wherein each electrochemical additive is not used with other electrochemical additives.

19. A solution as in Claim 14 wherein the electrochemical additive is selected from A) a mixture of vinylene carbonate and 1,3,2-dioxathiolane 2-oxide, B) a mixture of vinylene carbonate and 1,3-propane sultone, and C) a mixture of 1,3-propene sultone, tris(trimethylsilyl)phosphite, and 1,3,2-dioxathiolane 2,2-dioxide.

20. A solution as Claim 19 wherein the combined amount of the electrochemical additives in each mixture is about 0.25 wt% to about 5 wt%, relative to the total weight of the nonaqueous electrolyte solution.

21. A solution as in any of Claims 14-20 wherein 4-bromomethyl-1,3-dioxolan-2-one is in an amount of about 10 wt% or more bromine relative to the total weight of the solution.

22. A solution as in any of Claims 14-20 wherein the liquid electrolyte medium is ethylene carbonate, ethyl methyl carbonate, or a mixture thereof, and/or wherein the lithium-containing salt is lithium hexafluorophosphate.

23. A nonaqueous lithium battery comprising a positive electrode, a negative electrode, and a nonaqueous electrolyte solution as in any of Claims 14-22.

24. A process for producing a nonaqueous electrolyte solution for a lithium battery, which process comprises combining components comprising:

- i) a liquid electrolyte medium;
- ii) a lithium-containing salt; and
- iii) 4-bromomethyl-1,3-dioxolan-2-one; and
- iv) at least one electrochemical additive selected from:
 - a) unsaturated cyclic carbonates containing three to about six carbon atoms,
 - b) fluorine-containing saturated cyclic carbonates containing three to about five carbon atoms and one to about four fluorine atoms,
 - c) tris(trihydrocarbylsilyl) phosphites containing three to about nine carbon atoms,
 - d) trihydrocarbyl phosphates containing three to about twelve carbon atoms,
 - e) cyclic sultones containing three to about eight carbon atoms,
 - f) saturated cyclic hydrocarbyl sulfites having a 5-membered or 6-membered ring and containing two to about six carbon atoms,
 - g) saturated cyclic hydrocarbyl sulfates having a 5-membered or 6-membered ring and containing two to about six carbon atoms,
 - h) cyclic dioxadithio polyoxide compounds having a 6-membered, 7-membered, or 8-membered ring and containing two to about six carbon atoms,
 - i) another lithium-containing salt, and
 - j) mixtures of any two or more of the foregoing.

25. A process for producing a nonaqueous electrolyte solution for a lithium battery, which process comprises combining components comprising:

- i) a liquid electrolyte medium;
- ii) a lithium-containing salt; and
- iii) 4-bromomethyl-1,3-dioxolan-2-one; and
- iv) at least one electrochemical additive selected from vinylene carbonate, 4-fluoroethylene carbonate, tris(trimethylsilyl)phosphite, triallyl phosphate, 1,3-propane sultone, 1,3-propene sultone, 1,3,2-dioxathiolane 2-oxide, 1,3,2-dioxathiolane 2,2-dioxide, 1,5,2,4-dioxadithiane 2,2,4,4-tetroxide, lithium di(fluoro)(oxalato)borate, lithium bis(oxalato)borate, and mixtures of any two or more of these.

26. A nonaqueous electrolyte solution for a lithium battery, which solution comprises

- i) a liquid electrolyte medium;
- ii) a lithium-containing salt; and
- iii) 4-bromomethyl-1,3-dioxolan-2-one.

27. A solution as in Claim 26 wherein the 4-bromomethyl-1,3-dioxolan-2-one is in an amount of about 10 wt% or more bromine relative to the total weight of the solution.

28. A solution as in any of Claims 26-27 wherein the liquid electrolyte medium is ethylene carbonate, ethyl methyl carbonate, or a mixture thereof, and/or wherein the lithium-containing salt is lithium hexafluorophosphate.

29. A nonaqueous lithium battery comprising a positive electrode, a negative electrode, and a nonaqueous electrolyte solution as in any of Claims 26-28.

30. A process for producing a nonaqueous electrolyte solution for a lithium battery, which process comprises combining components comprising:

- i) a liquid electrolyte medium;
- ii) a lithium-containing salt; and
- iii) 4-bromomethyl-1,3-dioxolan-2-one.

31. A process as in Claim 30 wherein the 4-bromomethyl-1,3-dioxolan-2-one is in an amount of about 10 wt% or more bromine relative to the total weight of the solution.

32. A process as in any of Claims 30-31 wherein the liquid electrolyte medium is ethylene carbonate, ethyl methyl carbonate, or a mixture thereof, and/or wherein the lithium-containing salt is lithium hexafluorophosphate or lithium bis(oxalato)borate.