Claims

1. A stabilised Na-ion oxide P3 phase of formula Ia:

$$P3\text{-}Na_aFe_bMn_cM'_dO_e \qquad Ia$$

where:

$0.8 \leq a \leq 1.2$;

$0.4 \leq b \leq 0.6$;

$0.4 \leq c \leq 0.6$;

$0 \leq d \leq 0.1$;

$e \leq 2$; and

M' is selected from one or more of the group consisting of Ni, Cu, Mg, Ti, Zn and Ca, wherein the compound of formula Ia is suitable for use as a cathode active material in a Na-ion battery.

2. The compound of formula Ia according to Claim 1, where M' is Ti.

3. The compound of formula Ia according to Claim 1 or Claim 2, wherein each M' has an oxidation state of from +1 to +7.

4. The compound of formula Ia according to any one of Claims 1 to 3, wherein $1.9 < e \leq 2$.

5. The compound of formula Ia according to Claim 4, wherein one or more of the following apply:

(a) $0.8 \leq a \leq 1.0$;

(b) b is 0.5;

(c) $0.4 \leq c \leq 0.5$; and

(d) e is 2.

6. The compound of formula Ia according to any one of the preceding claims, wherein the compound is selected from:

(a) $P3\text{-}Na_{0.8}Fe_{0.5}Mn_{0.5}O_2$;

(b) $P3\text{-}Na_{0.8}Fe_{0.5}Mn_{0.45}Ti_{0.05}O_2$; and

(c) $P3\text{-}Na_{0.8}Fe_{0.5}Mn_{0.4}Ti_{0.1}O_2$.

7. A cathode comprising a stabilised Na-ion oxide P3 phase of formula Ia as described in any one of Claims 1 to 6 as an active material therein.

8. A sodium-ion battery comprising a cathode as described in Claim 7 or a stabilised Na-ion oxide P3 phase of formula Ia as described in any one of Claims 1 to 6 as an active material therein.

9. A method of forming a stabilised Na-ion oxide P3 phase of formula Ia as described in any one of Claims 1 to 6, the process comprising the steps of:

(a) providing a powder comprising a mixture of P3-$Na_aFe_bMn_cM'_dO_e$ and O3-$Na_aFe_bMn_cM'_dO_e$; and

(b) subjecting the powder to a temperature of from 350 to 700 ˚C with a heating rate of from 2 to 15 ˚C/min and a cooling rate of from 1 to 13 ˚C/min for a total period of from 2 to 24 hours, wherein:

$0.8 \leq a \leq 1.2$;

$0.4 \leq b \leq 0.6$;

$0.4 \leq c \leq 0.6$;

$0 \leq d \leq 0.1$;

$e \leq 2$; and

M' is selected from one or more of the group consisting of Ni, Cu, Mg, Ti, Zn and Ca.

10. The method of Claim 9, wherein the powder comprising a mixture of P3-$Na_aFe_bMn_cM'_dO_e$ and O3-$Na_aFe_bMn_cM'_dO_e$ is obtained using the method comprising the steps of:

(a) providing a powder comprising $Na_aFe_bMn_cM'_dO_e$; and

(b) subjecting the powder to a temperature of from 750 to 1050 ˚C with a heating rate of from 2 to 15 ˚C/min and a cooling rate of from 1 to 10 ˚C/min for a total period of from 6 to 20 hours, wherein:

$0.8 \leq a \leq 1.2$;

$0.4 \leq b \leq 0.6$;

$0.4 \leq c \leq 0.6$;

$0 \leq d \leq 0.1$;

$e \leq 2$; and

M' is selected from one or more of the group consisting of Ni, Cu, Mg, Ti, Zn and Ca.

11. The method of Claim 10, wherein the powder comprising $Na_aFe_bMn_cM'_dO_e$ is obtained by:

(ai) mixing Na, Fe, Mn and M' precursors with citric acid in a solvent;

(aii) adding NH_4OH to adjust the pH of the solution to 7.5 to 10.0; and

(aiii) drying the solution to obtain the powder comprising $Na_aFe_bMn_cM'_dO_e$.

12. A method of charging and discharging a Na-ion battery comprising a cathode as described in Claim 7 in a first charge/discharge cycle, wherein the method comprises the steps of charging and then discharging the Na-ion battery using a voltage window (cathode v/s Na/Na^+) of from 4.45±0.2 V to 2.0±0.5 V.

13. A method of charging and discharging a Na-ion battery comprising a cathode as described in Claim 7 in a subsequent (i.e. after a first) charge/discharge cycle, wherein the method comprises the steps of charging and then discharging the Na-ion battery using a voltage window (cathode v/s Na/Na^+) of from 4.2±0.05V to 2.0±0.5V.