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Bipolar Rechargeable Lithium Battery For High Power Applications

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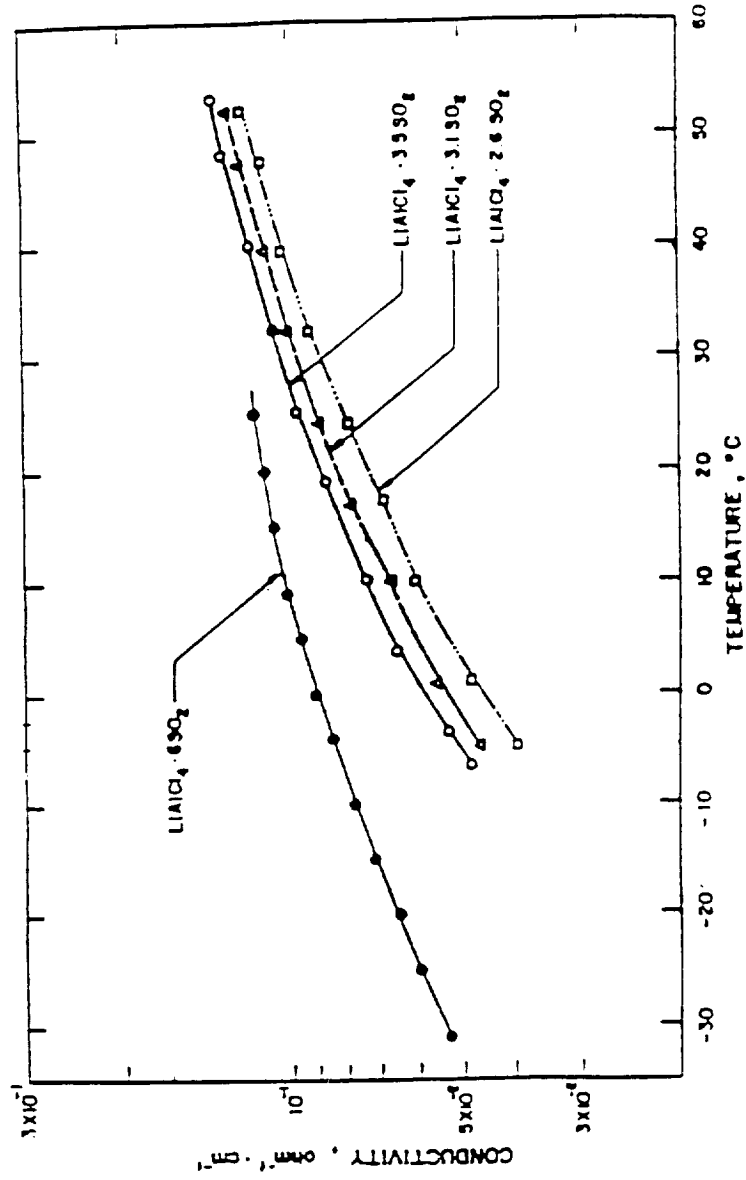
Yardney Technical Products, Inc.
82 MECHANIC STREET, PAWCATUCK CT 06379

Bipolar Rechargeable Lithium Battery: CELL CHEMISTRY

| | | |
|-------------------------------|---|---|
| Anode or Negative Electrode | : | Li |
| Cathode or Positive Electrode | : | CuCl ₂ |
| Electrolyte | : | SO ₂ based LiAlCl ₄ |
| OCV | : | 3.45V versus Li |

NO organic electrolytes offer as high conductivity as SO₂-based electrolytes

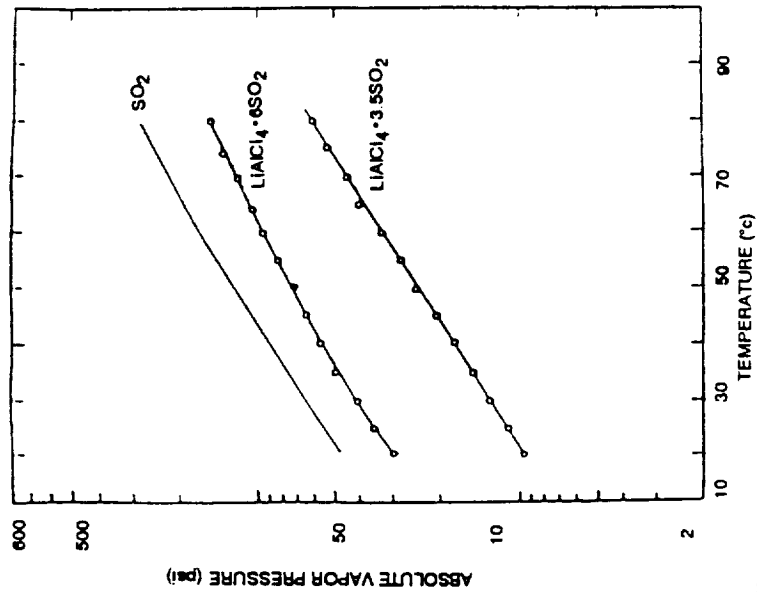
Conductivity of LiAlCl₄/SO₂ Electrolytes at Various Temperatures



Kuo et al, Duracell Final Report, Contract No. DOE-DE-AC01-80ER-10191 (1985)

Vapor-pressure lower than atmospheric pressure can be achieved with SO_2 -based electrolytes.

Vapor Pressures of $\text{LiAlCl}_4/\text{SO}_2$ Electrolytes at Various Temperatures



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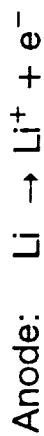
SO₂ based Li-ion conducting electrolytes offer several advantages

- High ionic conductivity ($1 \cdot 1 \times 10^{-2} \text{ Scm}^{-1}$)
- Excellent electrochemical voltage window
- Limited overcharge tolerance
- Very low shelf – discharge rate (<0.1% per month)
- Insignificant Li – anode passivation

Bipolar Rechargeable Lithium Battery: REACTION MECHANISMS

The use of high surface area carbon and SO_2 -based LiAlCl_4 electrolyte provides extra capacity before SO_2 -reduction occurs.

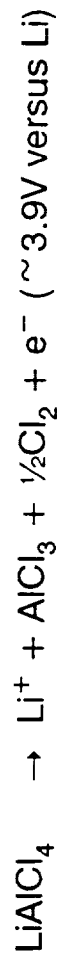
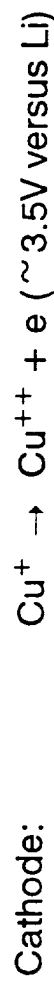
Discharge



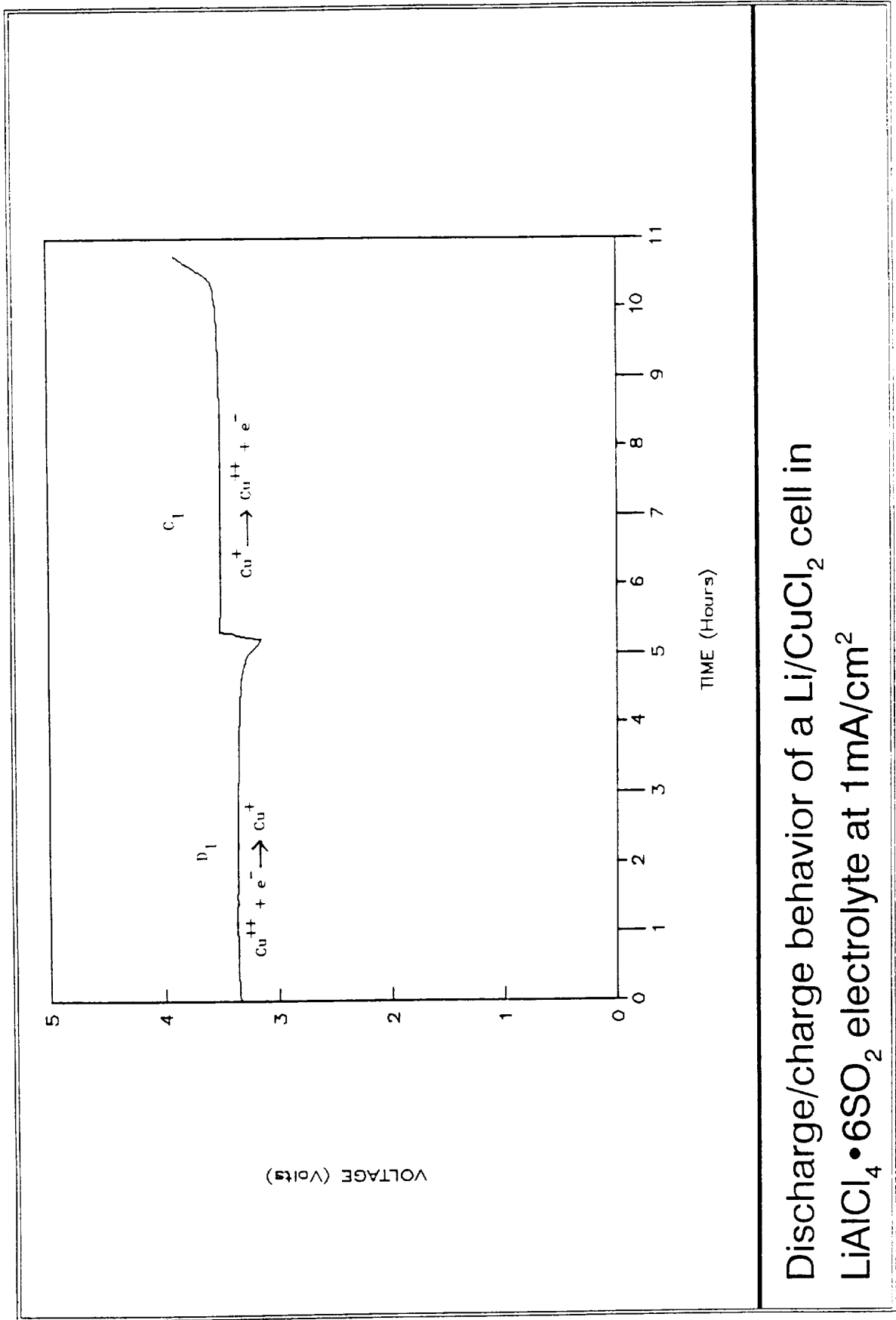
Cathode:

1. $\text{Cu}^{++} + \text{e}^- \rightarrow \text{Cu}^+$ (~ 3.4 versus Li)
2. $\text{LiAlCl}_4 \cdot 3\text{SO}_2 + \text{x C} + 3\text{e}^- \rightarrow \text{LiClAl} \begin{array}{c} \text{OSO} \\ \text{OSO} \\ \text{OSO} \end{array} + \text{Cx} + 3\text{Cl}^-$
3. $2\text{SO}_2 + 2\text{e}^- \rightarrow \text{S}_2\text{O}_4^{2-}$ ($\sim 2.8\text{V}$ versus Li)
4. $\text{Cu}^+ + \text{e}^- \rightarrow \text{Cu}^0$ ($\sim 2.5\text{V}$ versus Li)

Charge

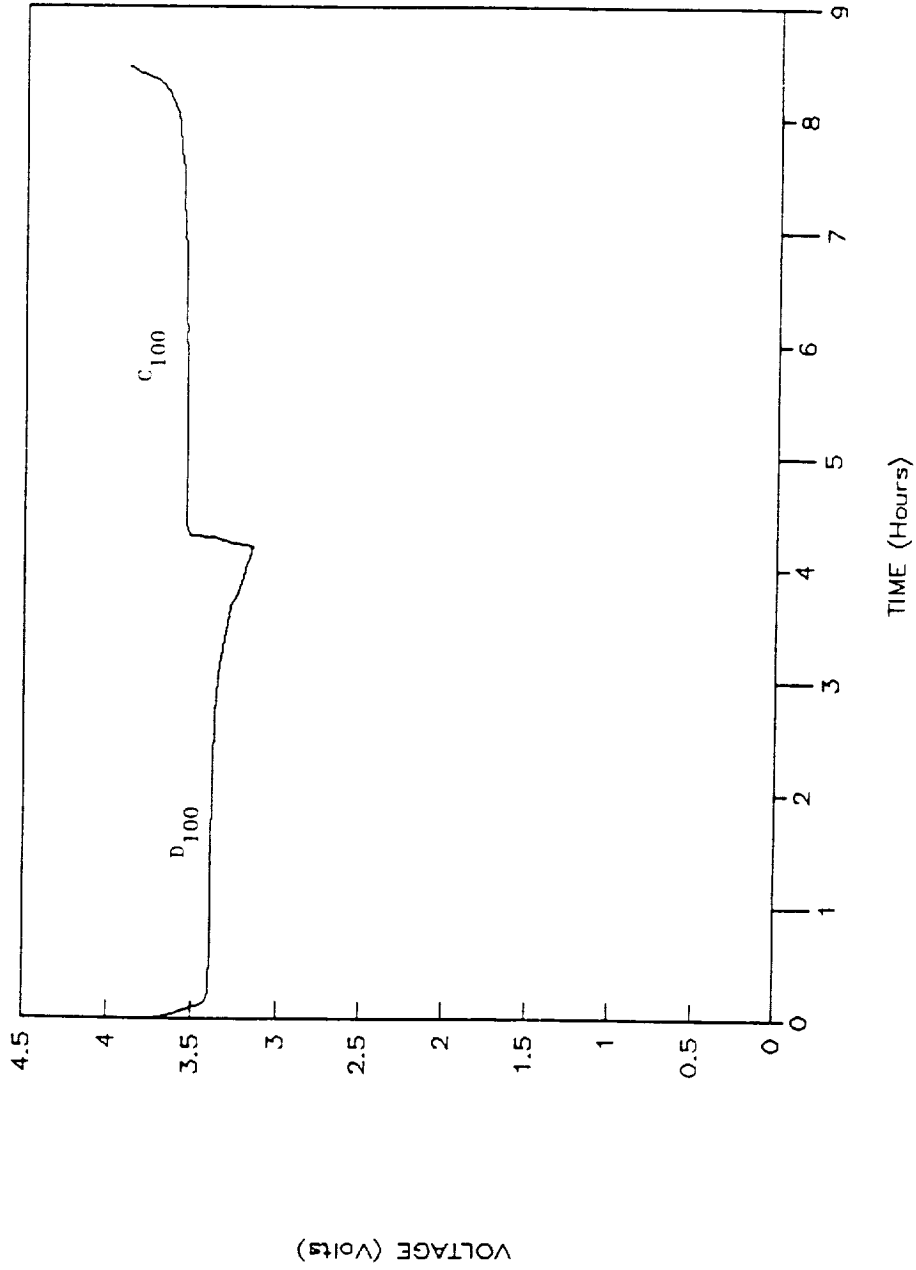


Li/CuCl₂ Rechargeable Cells: CYCLING BEHAVIOR



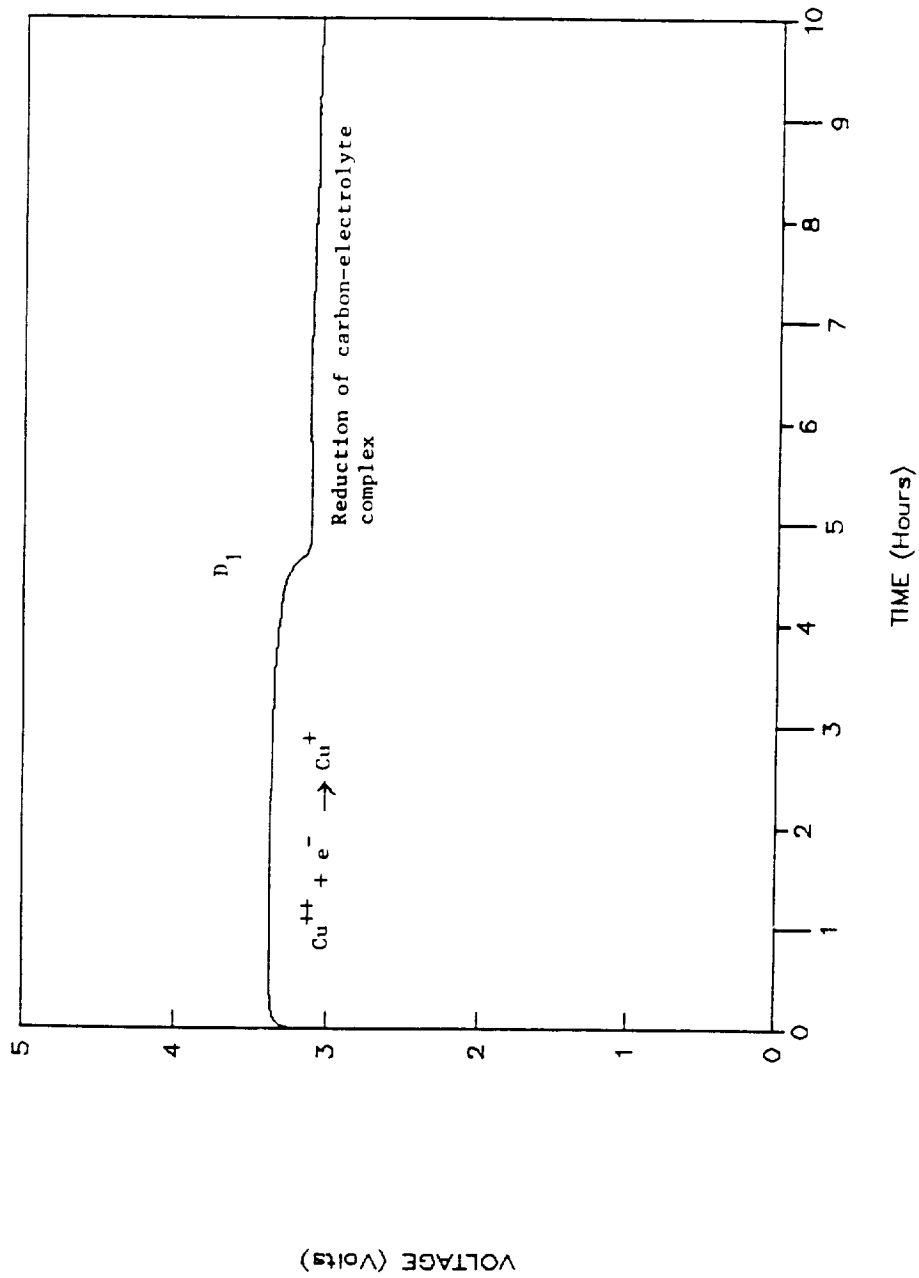
Discharge/charge behavior of a Li/CuCl₂ cell in
LiAlCl₄•6SO₂ electrolyte at 1mA/cm²

Li/CuCl₂ Rechargeable Cells: CYCLING BEHAVIOR



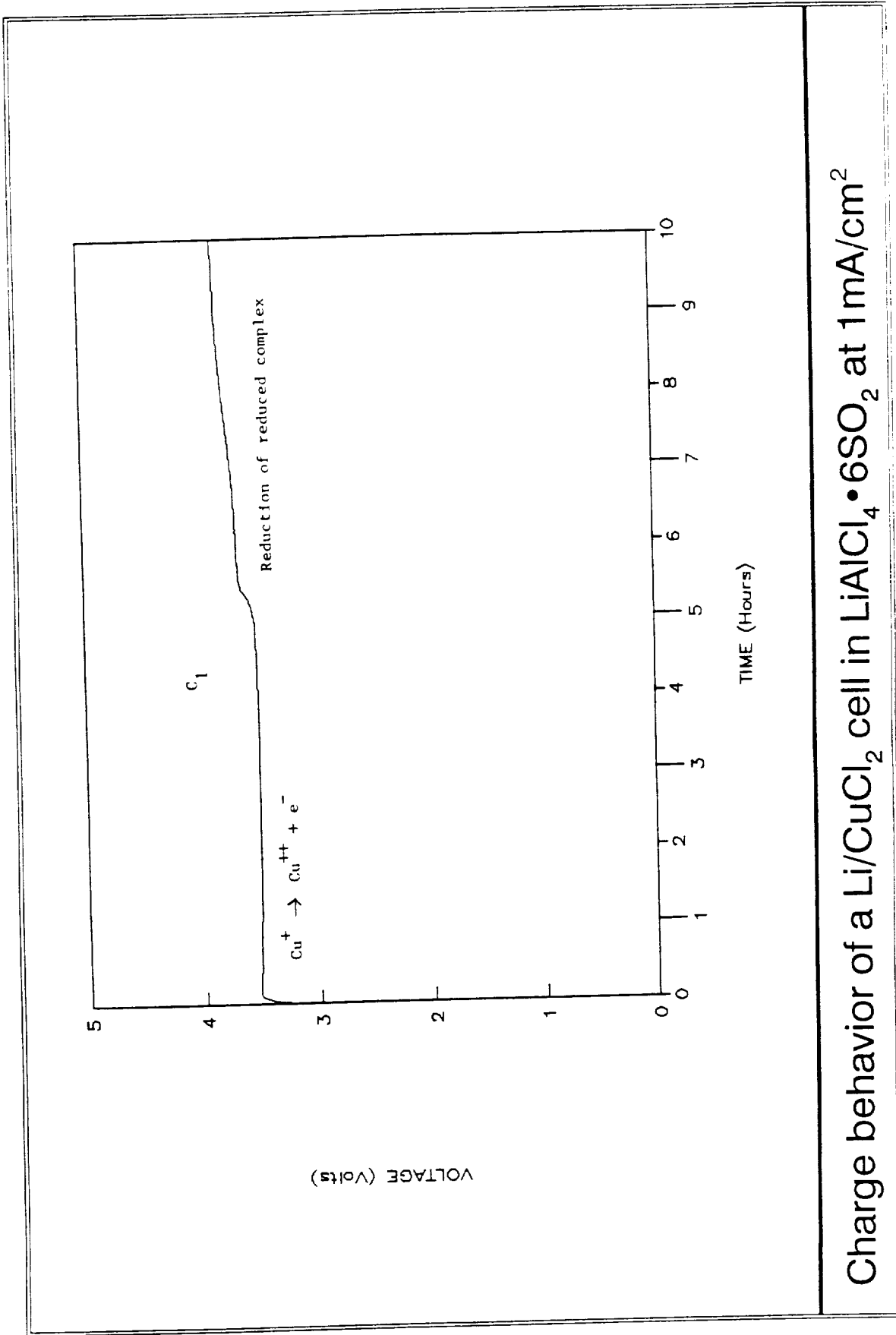
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Li/CuCl₂ Rechargeable Cells: CYCLING BEHAVIOR



Discharge behavior of a Li/CuCl₂ rechargeable cell in
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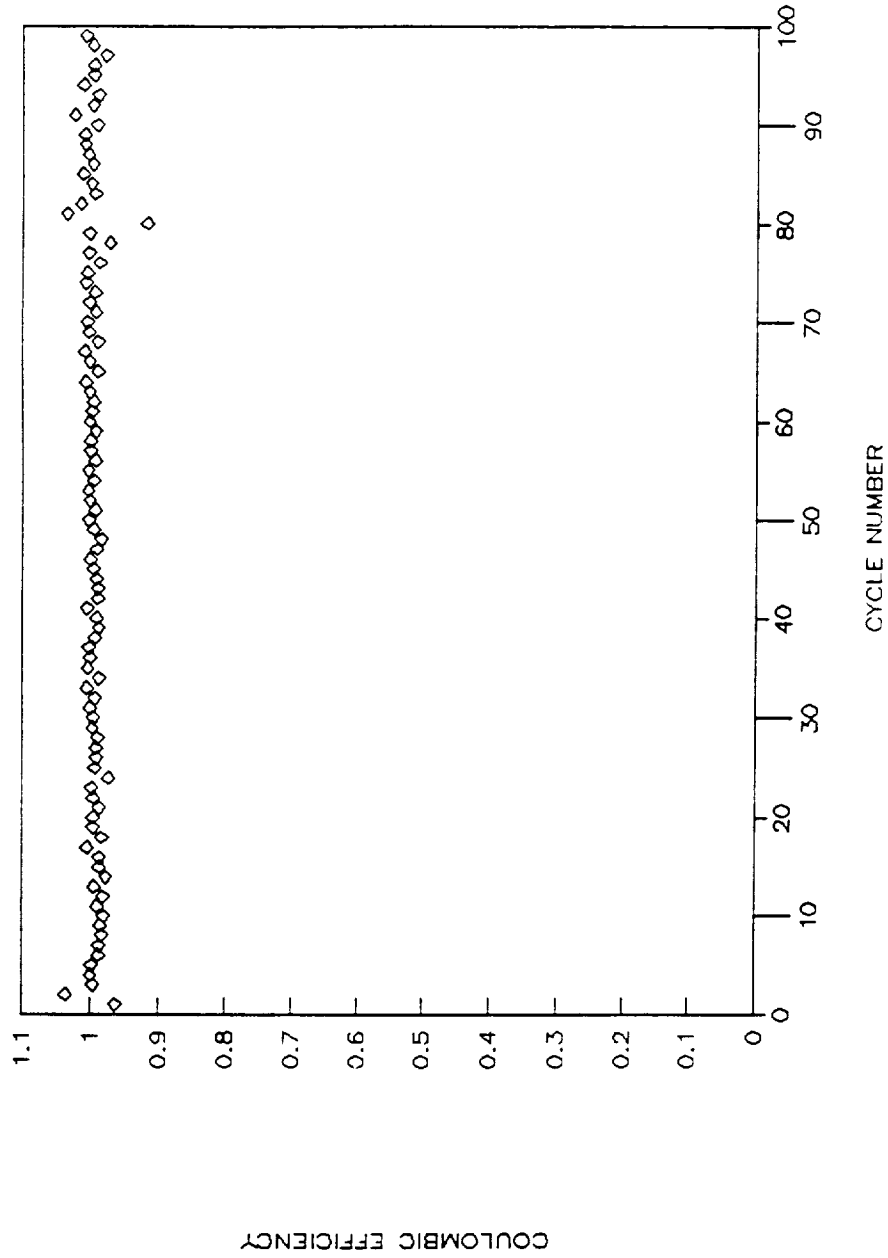
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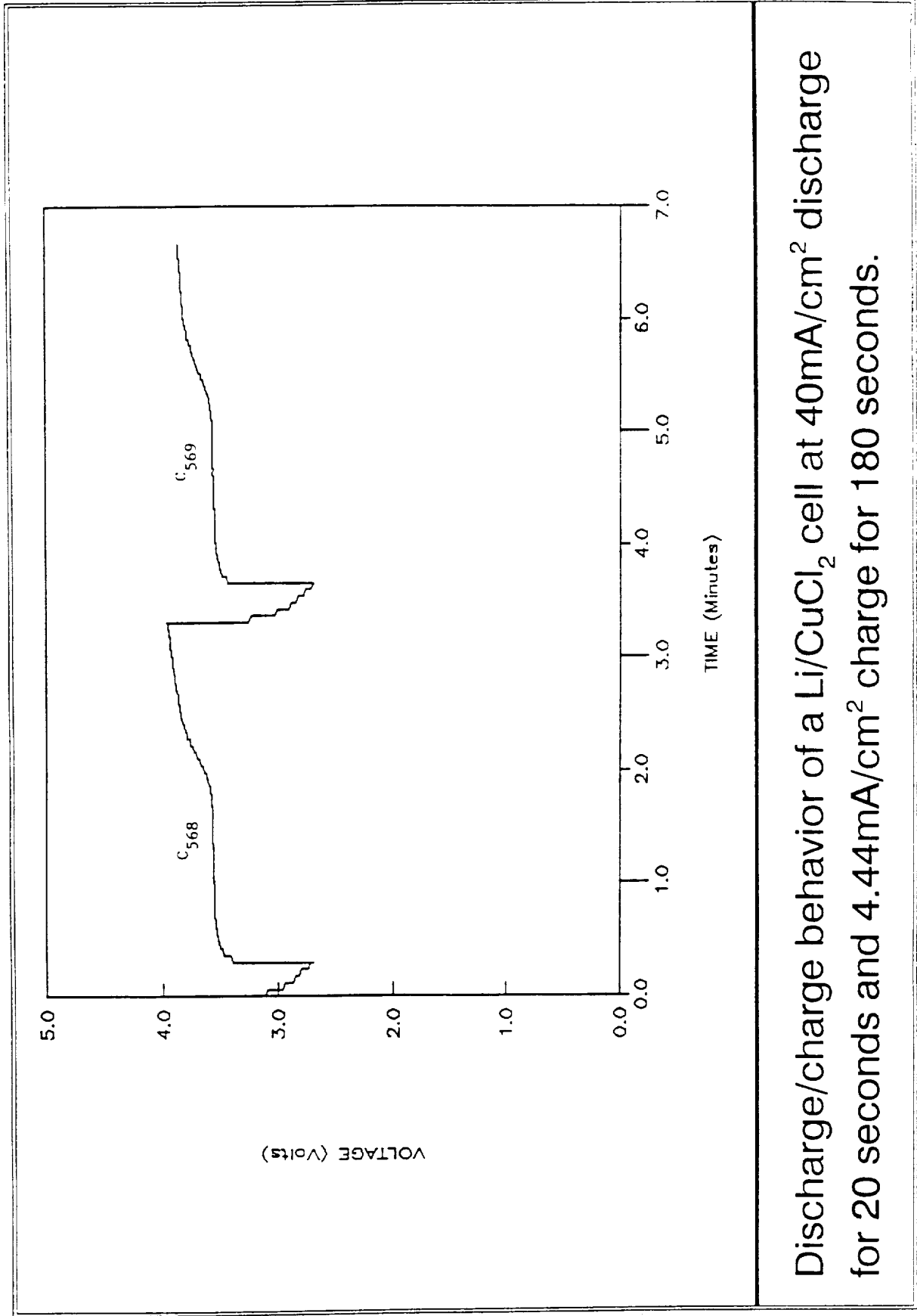
Li/CuCl₂ Rechargeable Cells: CYCLING BEHAVIOR

Coulombic efficiency of 1 shows excellent cycling behavior



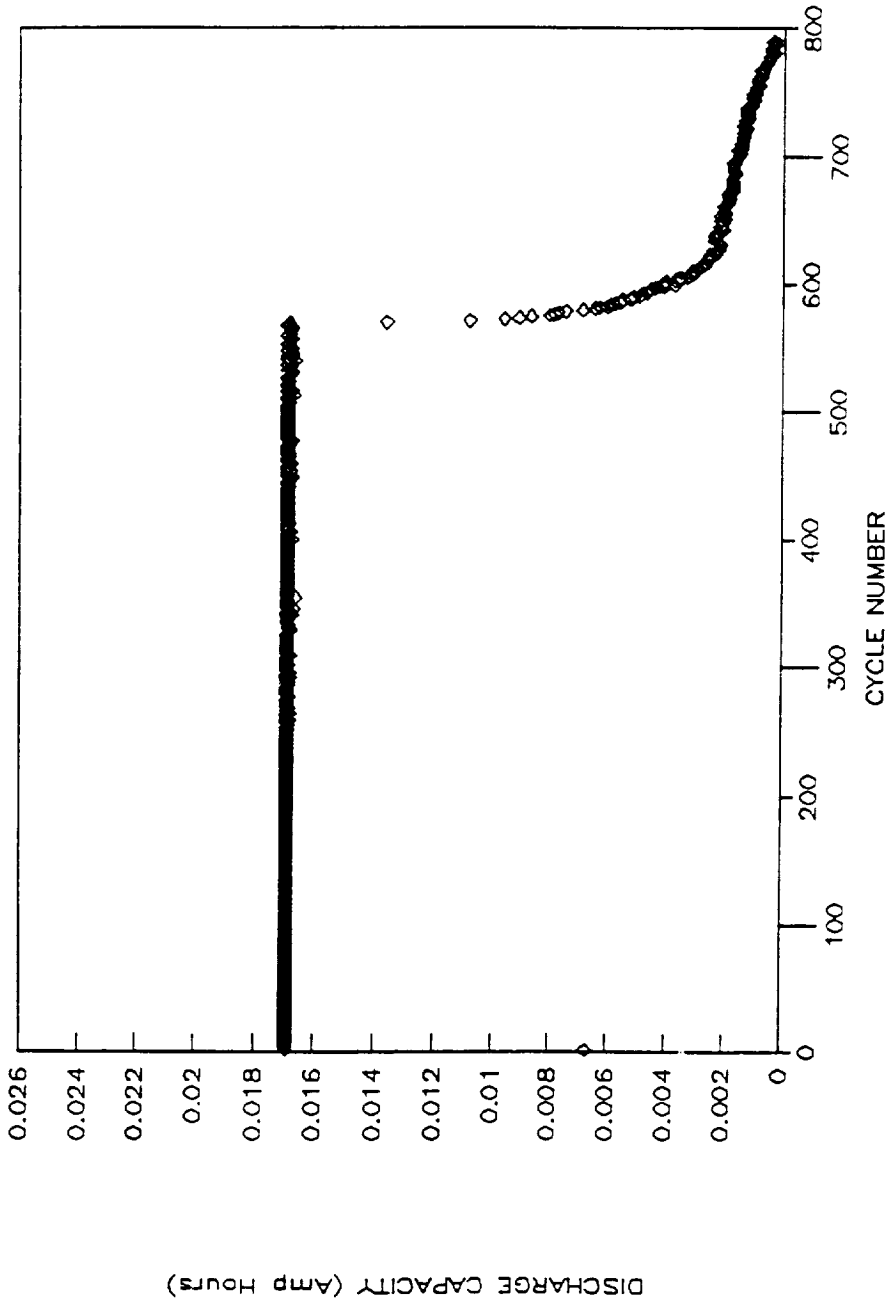
Coulombic efficiency of a Li/CuCl₂ cell at 1mA/cm² discharge/charge rate

Bipolar Lithium Rechargeable Batteries: CYCLING BEHAVIOR



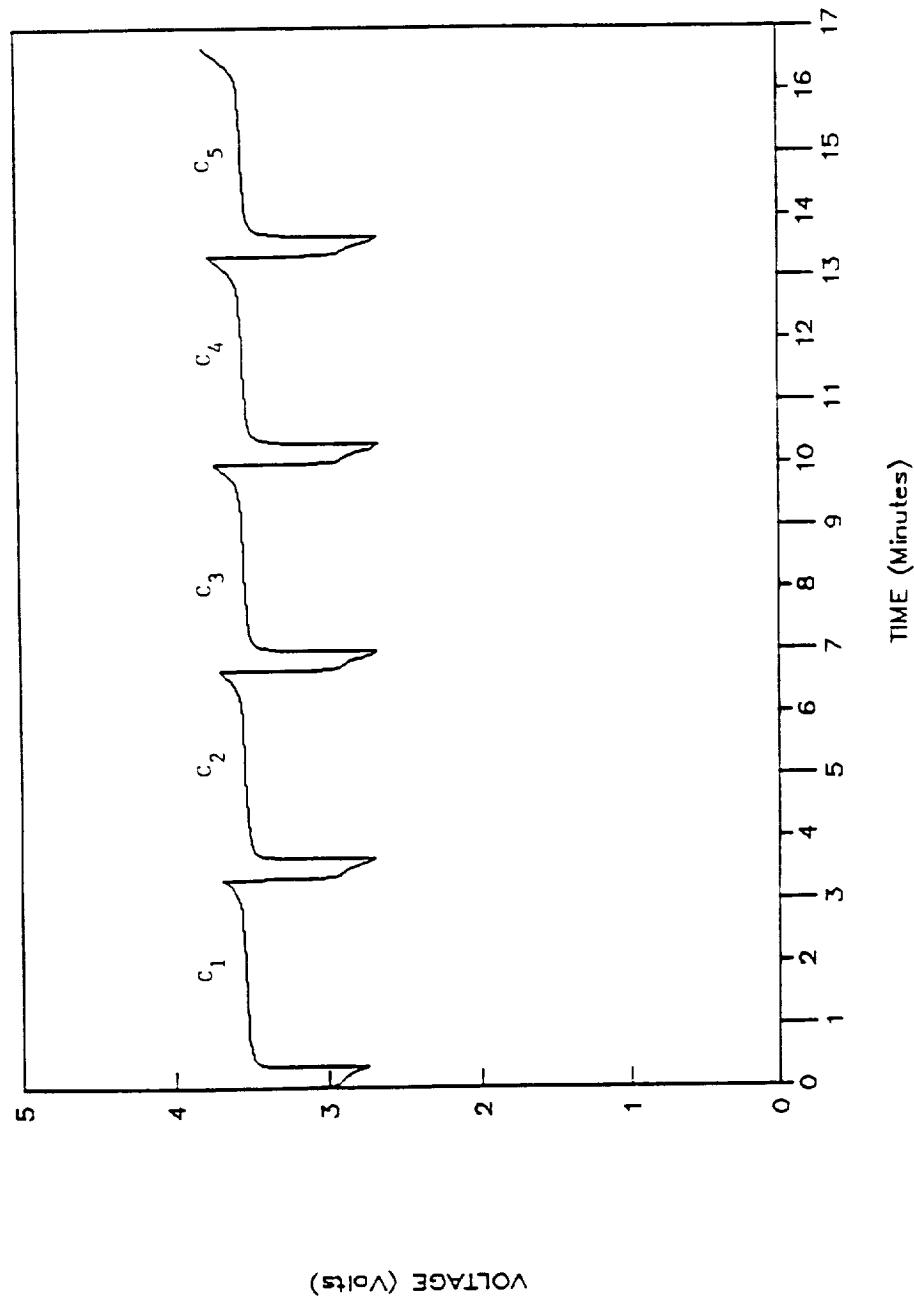
Discharge/charge behavior of a Li/CuCl₂ cell at 40mA/cm² discharge for 20 seconds and 4.44mA/cm² charge for 180 seconds.

Bipolar Lithium Rechargeable Batteries: CYCLE LIFE



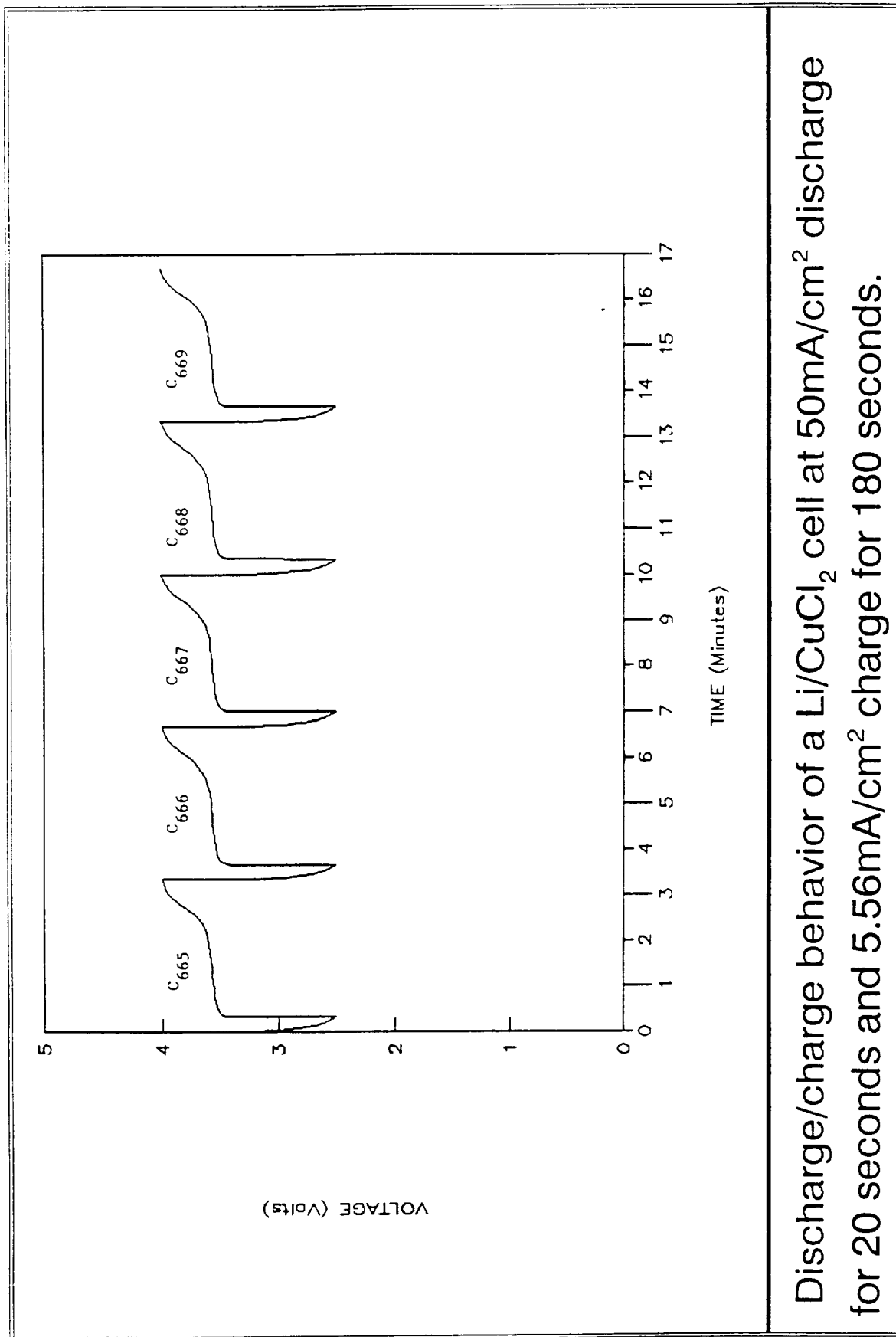
Cycle number vs capacity of a Li/LuCl₂ cell at 40mA/cm² discharge for 20 seconds and 4.44mA/cm² charge for 180 seconds. Voltage limits 2.5–4.0 V.

Bipolar Lithium Rechargeable Batteries: CYCLING BEHAVIOR

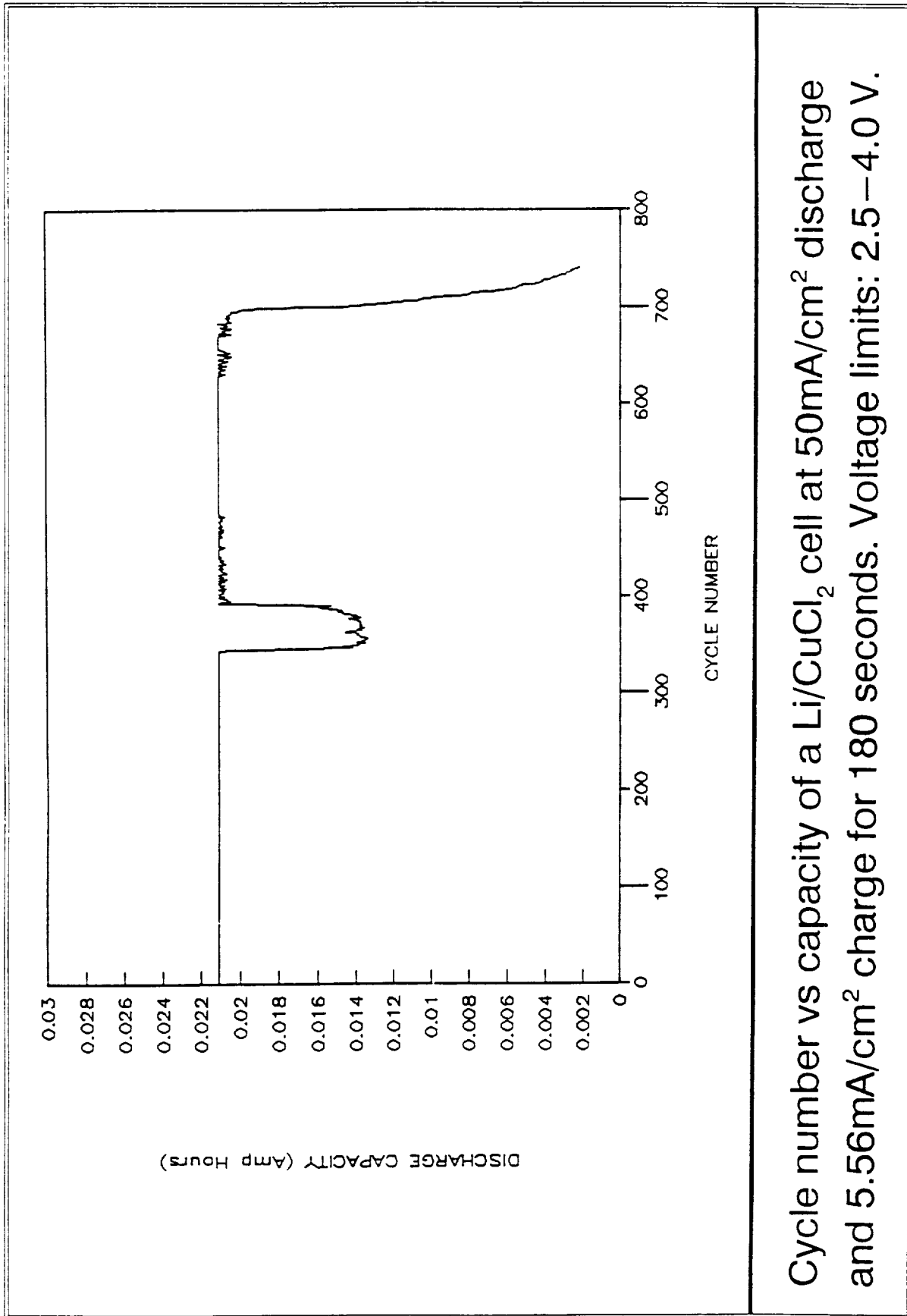


Discharge/charge behavior of a Li/CuCl₂ cell at 50mA/cm² discharge for 20 seconds and 5.56mA/cm² charge for 180 seconds.

Bipolar Lithium Rechargeable Batteries: CYCLING BEHAVIOR

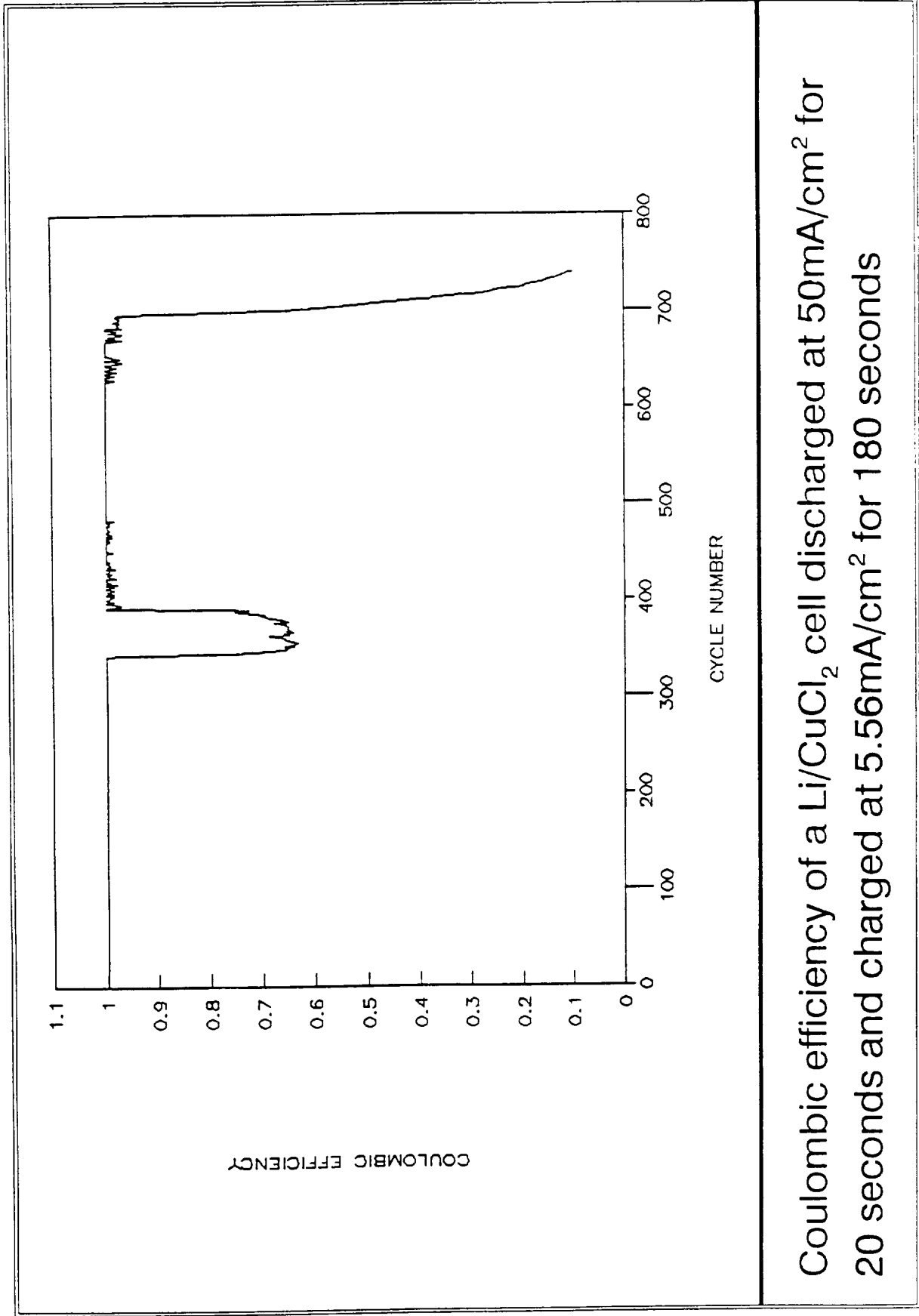


Bipolar Lithium Rechargeable Batteries: CYCLE LIFE



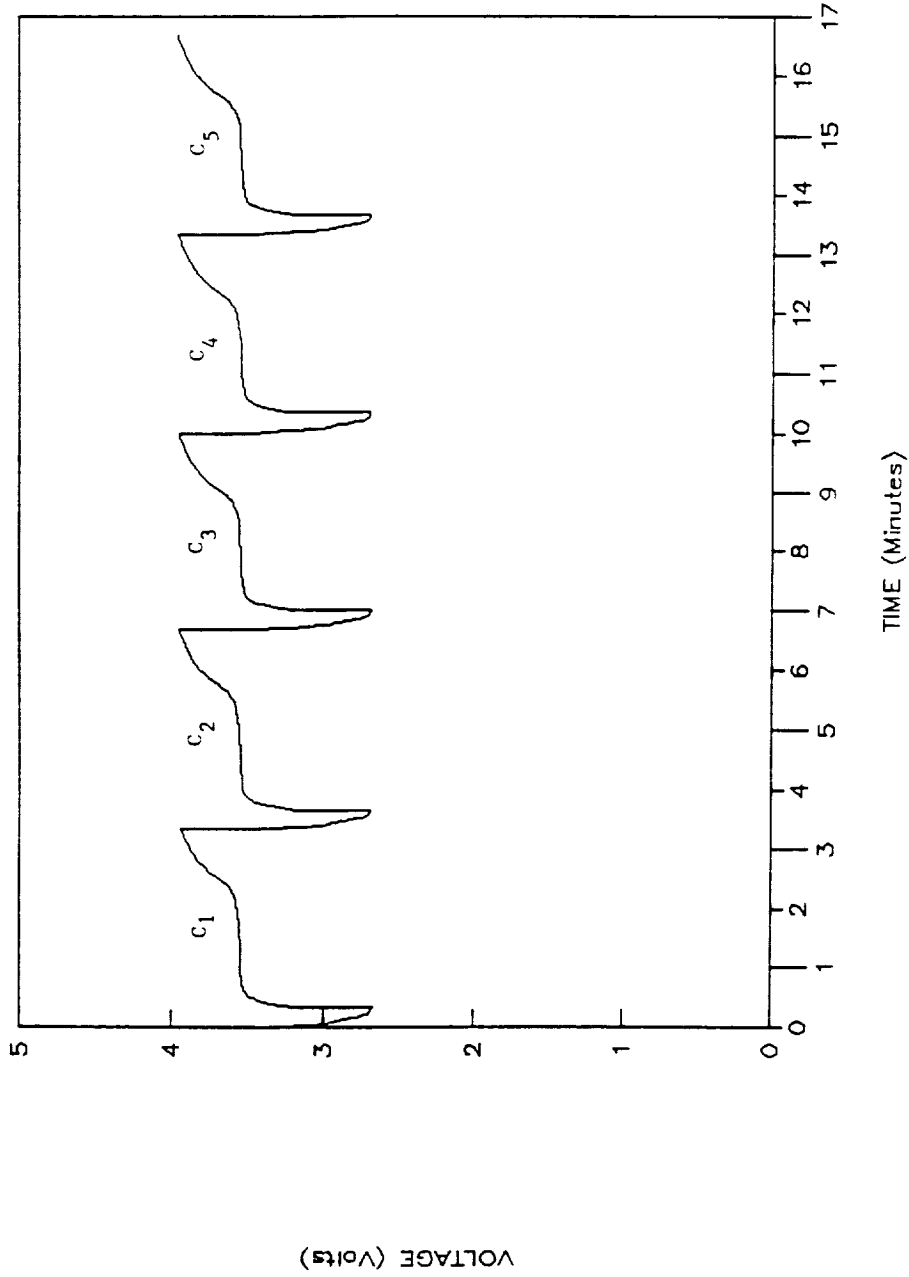
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Bipolar Lithium Rechargeable Batteries: CYCLING BEHAVIOR



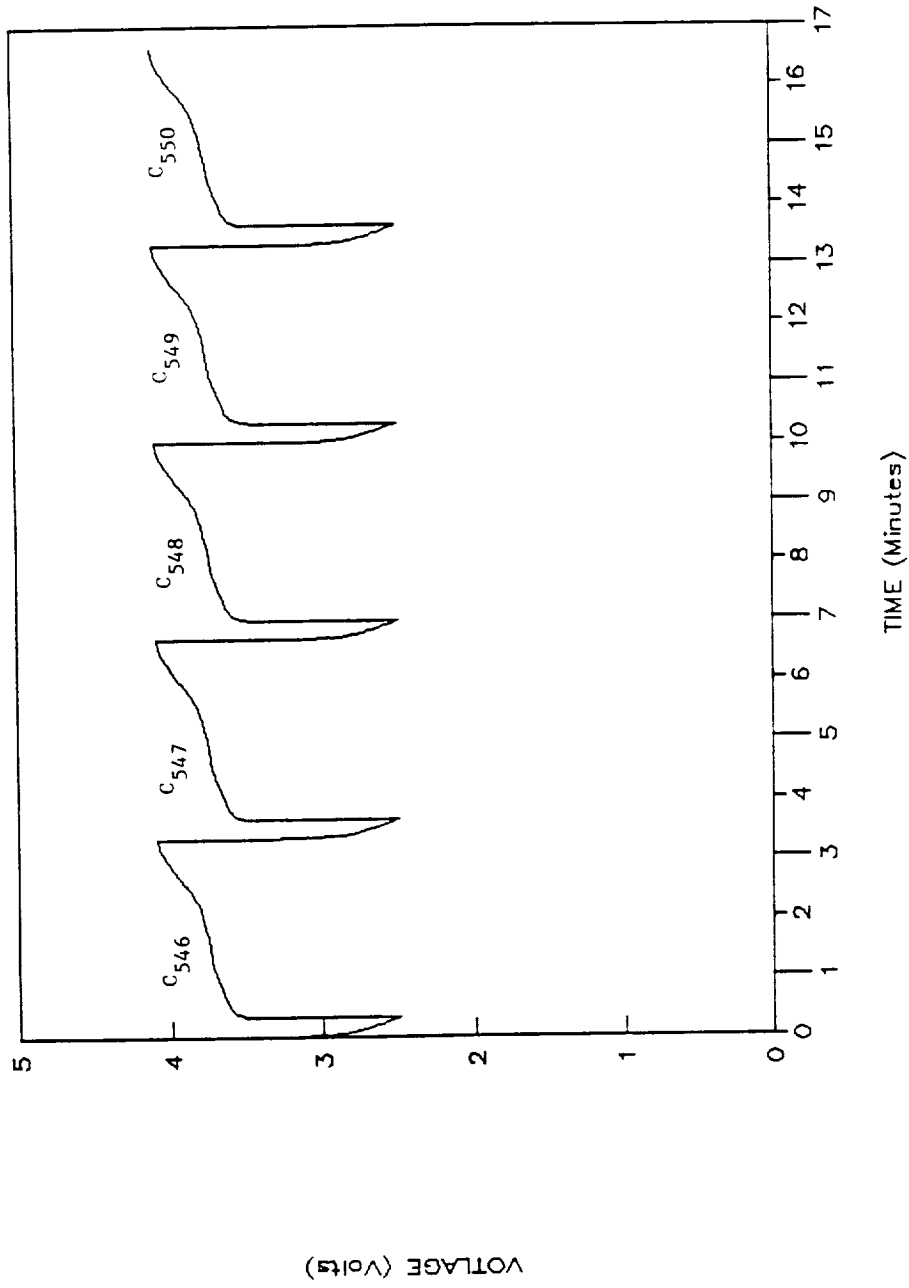
Coulombic efficiency of a Li/CuCl₂ cell discharged at 50mA/cm² for 20 seconds and charged at 5.56mA/cm² for 180 seconds

Bipolar Lithium Rechargeable Batteries: CYCLING BEHAVIOR



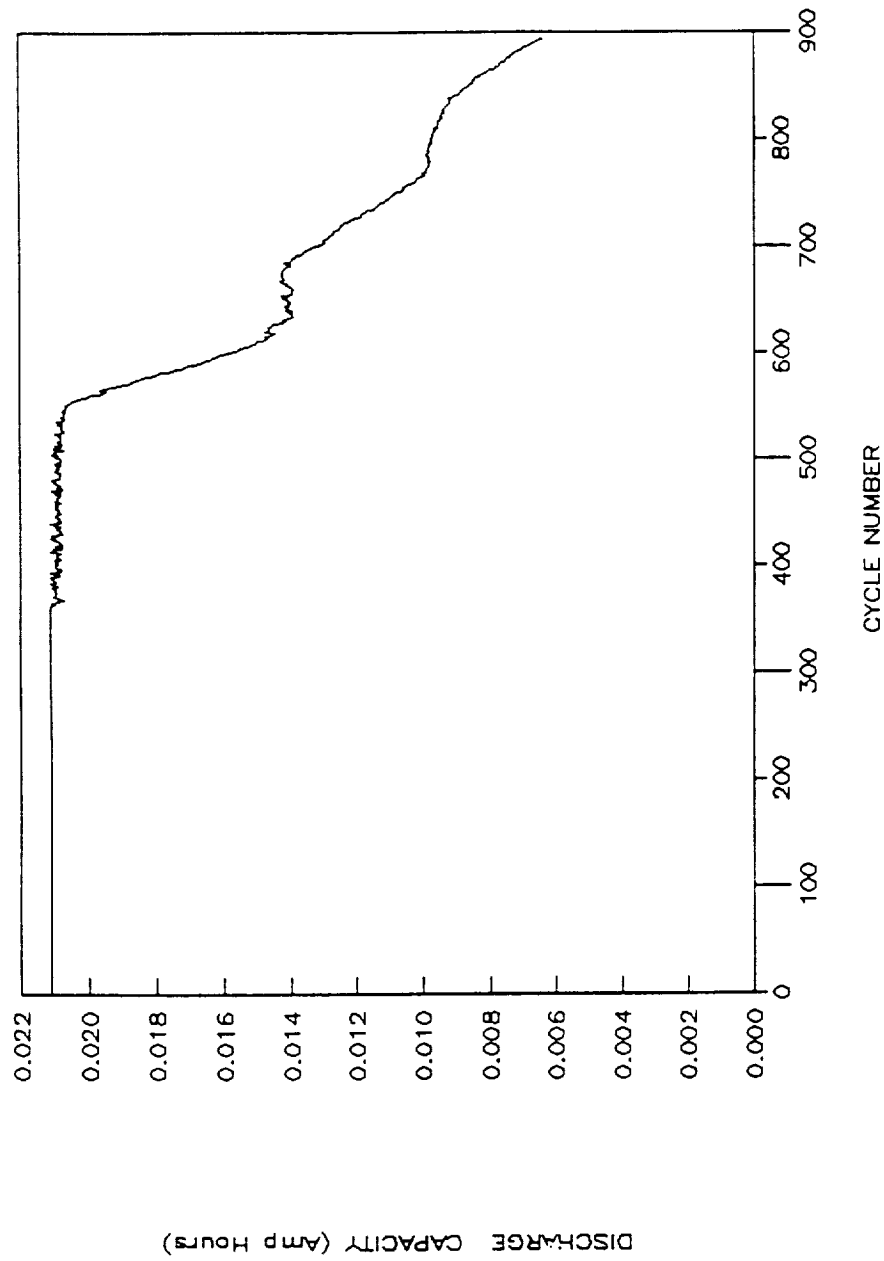
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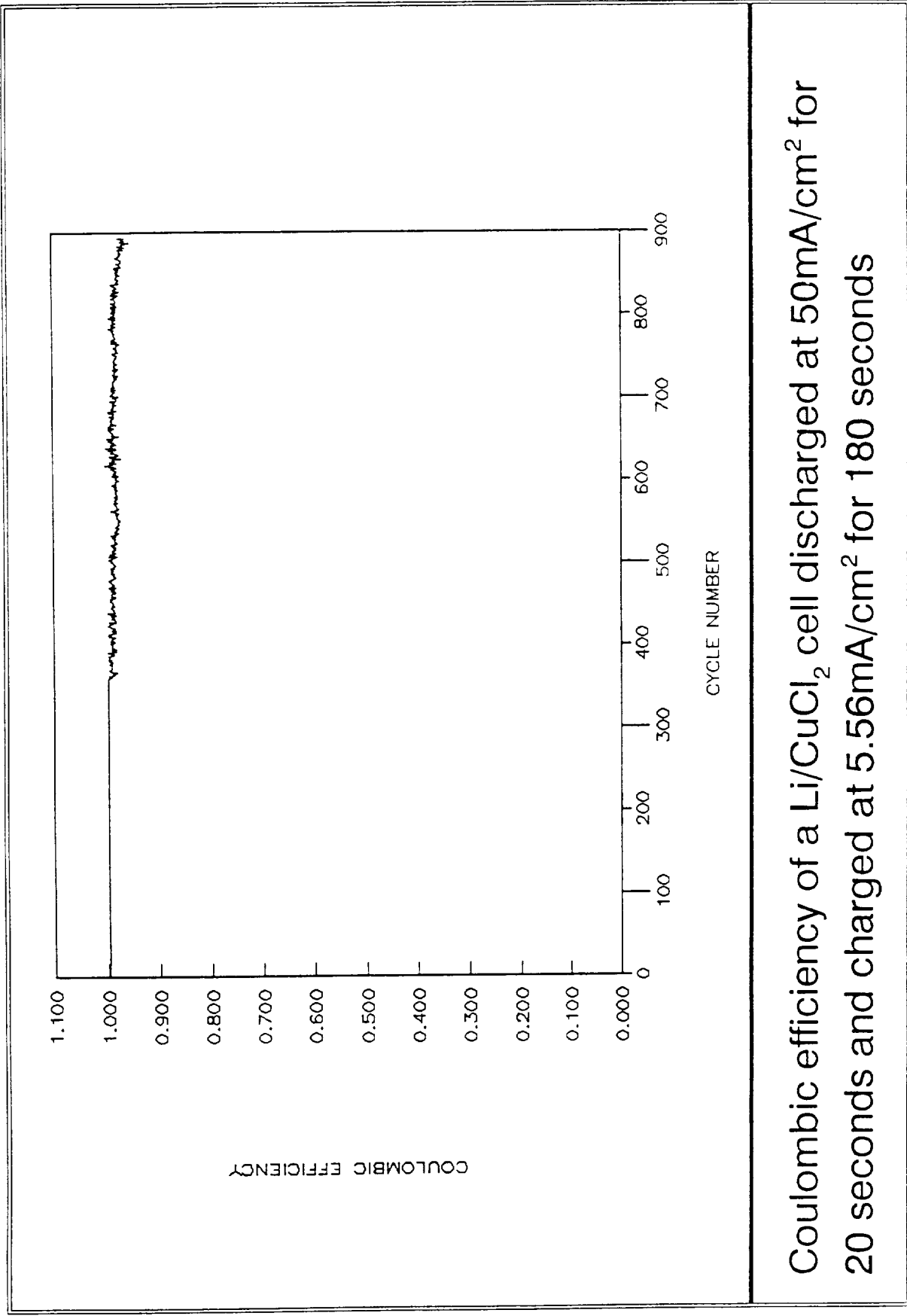
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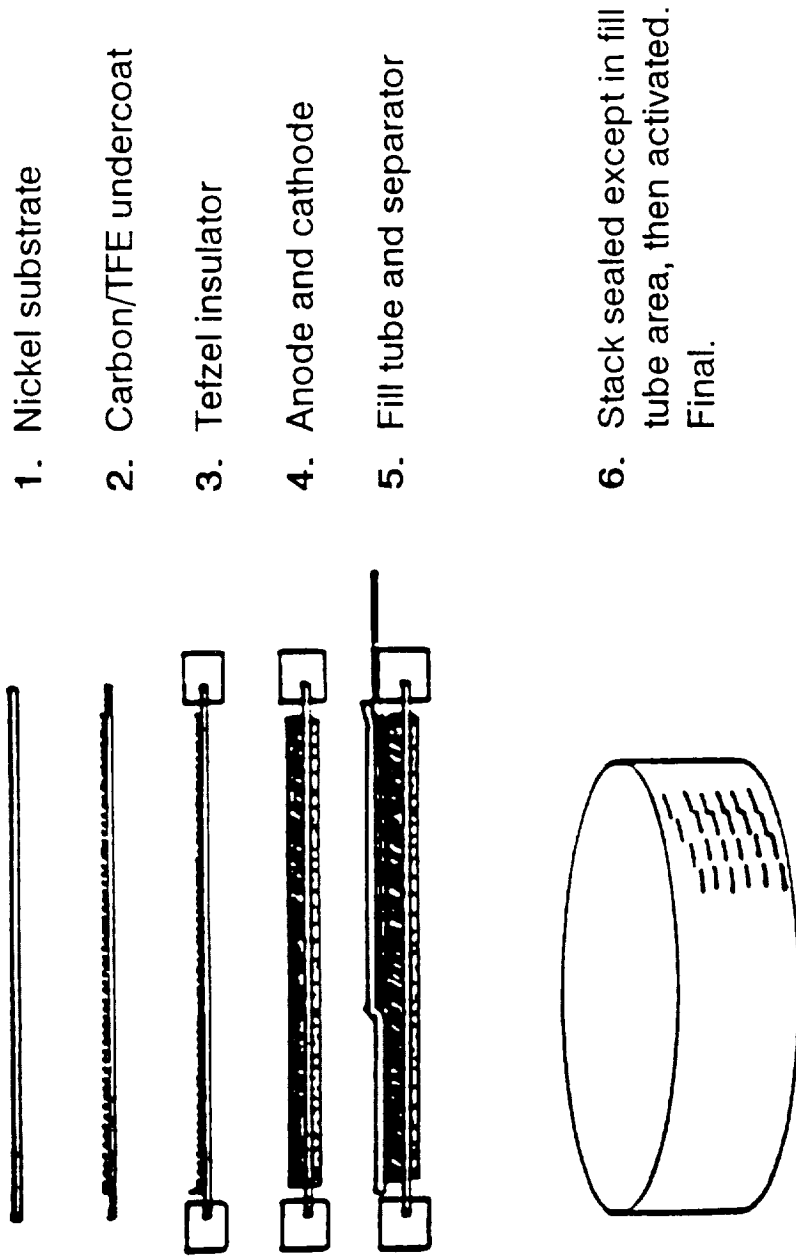
Cycle number vs capacity of a Li/LuCl₂ cell at 50mA/cm² discharge for 20 seconds and 5.56mA/cm² charge for 180 seconds. Voltage limits 2.5 – 4.0 V.

Bipolar Lithium Rechargeable Batteries: CYCLING BEHAVIOR



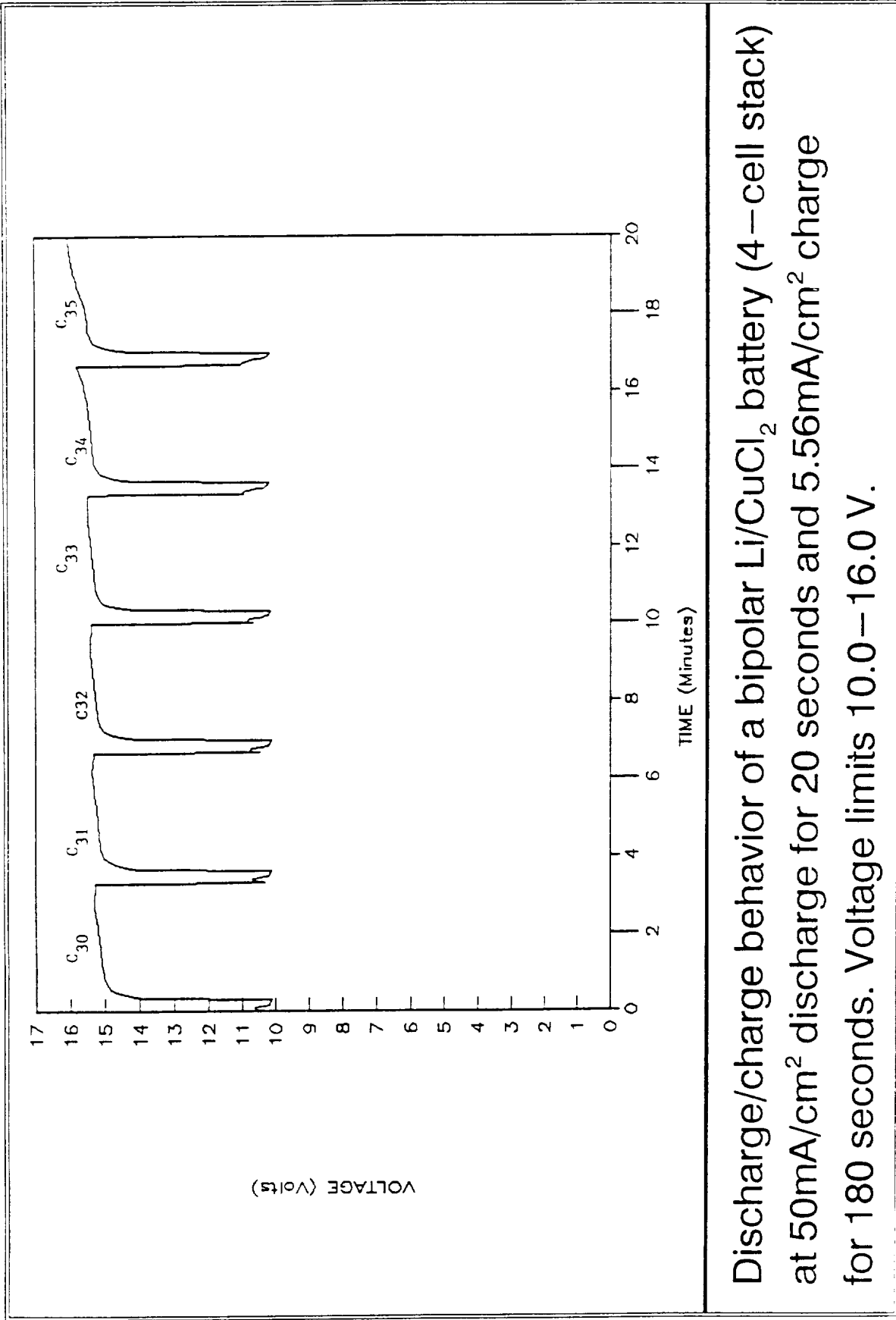
Coulombic efficiency of a Li/CuCl₂ cell discharged at 50mA/cm² for 20 seconds and charged at 5.56mA/cm² for 180 seconds

Bipolar Lithium Rechargeable Batteries: CELL ASSEMBLY



BIPOLAR STACK ASSEMBLY SEQUENCE

Bipolar Lithium Rechargeable Batteries: CYCLING BEHAVIOR



Discharge/charge behavior of a bipolar Li/CuCl₂ battery (4-cell stack) at 50mA/cm² discharge for 20 seconds and 5.56mA/cm² charge for 180 seconds. Voltage limits 10.0–16.0 V.

Bipolar Rechargeable Lithium Battery

Based on the present state-of-the-art of bipolar rechargeable lithium batteries, a cumulative specific power of 1mW/kg and specific energy of 6kWh/kg can be achieved

Development of a 270V bipolar rechargeable battery

REQUIREMENTS:

Discharge: 20 seconds at 50mA/cm² (Total = 30A)

Average operating voltage: 270 V

Charge: 180 seconds at 5.56mA/cm² (Total=3.33A)

Charge cut-off voltage: 360 V

Total number of cycles: 800 cycles

TOTAL WEIGHT OF BIPOLAR BATTERY: 6 kg

SPECIFIC POWER = $\frac{270 \times 30}{6}$ w/kg = 1.35kW/kg