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SHORT COMMUNICATION

# *State-of-charge measurement of the lithium–carbon monofluoride battery by chronopotentiometry*

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## 1. Introduction

Previous attempts to measure the state-of-charge of commercial lithium–carbon monofluoride batteries (Matsushita standard 2/3 A size) by impedance techniques [1] failed because of insensitivities of the various impedance parameters or because of time-after-discharge dependences. Basically, the problem is that equilibrium conditions for the battery are difficult to achieve, owing to extremely slow rates of recovery after discharge. Fortunately, as will be shown here, chronopotentiometry [2] provides a simple, convenient and fast means of measuring the state-of-charge of these batteries without excessive losses.

## 2. Experimental details

The batteries were the same as those used previously [1]. They had been discharged through a 6 Ω resistor for various times ~15 months before this study. Their states-of-charge (1 − coulombs removed/4300) were between 1.0 and 0.3, based on rated capacities of 4300 C at 60 Ω load. A fresh battery was also studied both before and after a similar 1000 C discharge. An EG & G PARC 173 potentiostat/galvanostat was used to apply 0.5 or 1.0 A currents to these batteries, and potential drops were recorded on a Houston Instrument Omniscribe recorder.

## 3. Results and discussion

Figs 1 and 2 show the voltage versus time traces for discharges of 0.5 and 1.0 A, respectively. Notice that even though replicate runs are not in total agreement, the time at which constant voltage is obtained, herein defined as the 'transition time', is reproducible. The transition time varies linearly with state-of-charge (see Fig. 3, curves 1 and 2) provided state-of-charge does not fall below about 0.5 (2000 C removed), depending upon load. Below 0.5 a constant voltage is not achieved; however, the voltages obtained after 1 min of discharge are quite reproducible and vary monotonically with state-of-charge (Fig. 3, curves 3 and 4). The data points marked (×) were obtained with the freshly discharged battery and are consistent with the other data, indicating that the state-of-charge does not depend upon the time after discharge.

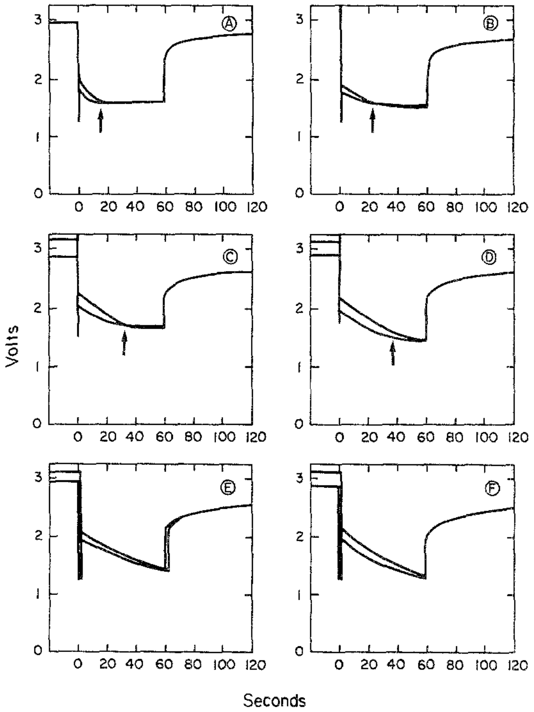

Fig. 1. Voltage versus time responses of six batteries, each at a different state-of-charge. Responses caused by 0.5 A, 60 s discharge. Transition times are indicated by arrows. Each battery was tested twice. Total coulombs removed after the first discharge: (A) 520; (B) 1050; (C) 1590; (D) 2030; (E) 2560; (F) 2920.

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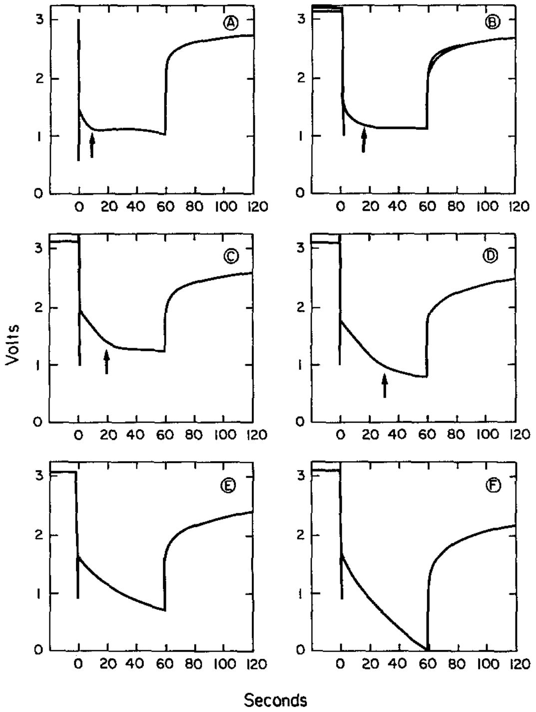

Fig. 2. Voltage versus time responses of the six batteries indicated in Fig. 1. Responses caused by 1.0 A, 60 s discharge. Transition times are indicated by arrows. Total coulombs removed after discharge: (A) 610; (B) 1140; (C) 1680; (D) 2120; (E) 2650; (F) 3010.

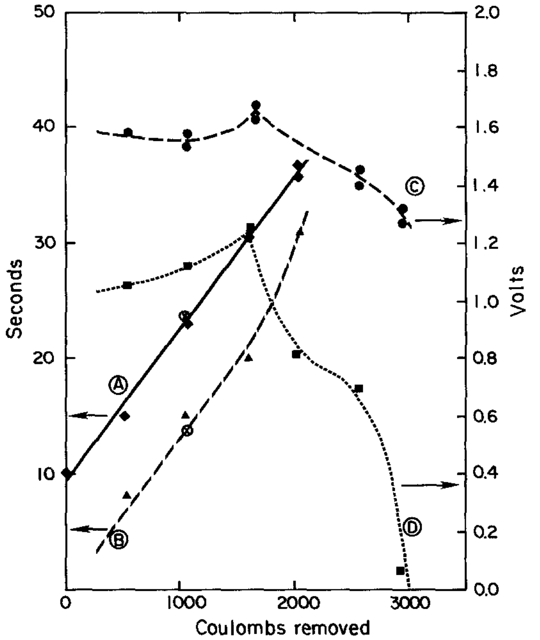

Fig. 3. Plots of transition times and battery voltages under load versus coulombs removed. (A) Transition times under 0.5 A load. (B) Transition times under 1.0 A load. (C) Battery voltage at 60 s under 0.5 A load. (D) Battery voltage at 60 s under 1.0 A load.

In practice, the load current chosen for a given state-of-charge determination may depend upon the range of interest. Time can be saved at high states-of-charge if high load currents are used. Less charge will be consumed if the current is returned to zero immediately after the transition time. For intermediate to low states-of-charge a lower current would be preferable. In any case, no more than 60 C (1.4% of the maximum rated capacity) need be removed.

## References

[1] J. R. Sandifer and M. R. Suchanski, *J. Appl. Electrochem.* **14** (1984) 329.

[2] A. J. Bard and L. R. Faulkner, 'Electrochemical Methods, Fundamentals and Applications', Wiley, New York (1980) Chap. 7.