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Li-Ion

# Lithium Ion
## technical handbook

smart electronics

# Table of Contents





## 1 Overview of the Lithium Ion Battery

Lithium Ion chemistry has evolved as a way to provide more energy in a smaller and lighter package. Its appearance has been the result of extending the chemistry of Lithium metal in primary and secondary cells. Eliminating Lithium metal from the cell allows the cell to cycle reversibly, safely for many hundreds of cycles. New materials have been developed which cost considerably more than those made for Nickel Metal Hydride (NiMH) and Nickel Cadmium (NiCd),cells. The higher cost has been based on the recovery of the development cost and lower production volumes. It is possible that in the future the cost per watt-hr will be significantly less than competitive chemistries, while providing superior energy density.

### 1.1 Principles

Lithium, in this cell, exists in the chemical matrix within the positive and negative electrodes and in the electrolyte. The cell gets its name from the Lithium Ion, because there is no metallic Lithium in the system.

The charge discharge reaction for $LiCoO_2$ is listed below. See schematic in Figure 2.1.

**Table 1.1 Charge Discharge Reaction**

**Charge**

| | | | |
|---|---|---|---|
| Positive | $LiCoO_2 - xLi^+ + xe^-$ | $\Rightarrow$ | $Li_{1-x}CoO_2$ |
| Negative | $6C + xLi^+ + e^-$ | $\Rightarrow$ | $Li_xC_6$ |
| Overall | $LiCoO_2 + 6C$ | $\Rightarrow$ | $Li_{1-x}CoO_2 + Li_xC_6$ |

### 1.2 General Features

- High energy density - greater than 300 Wh/L and 150 Wh/kg: about 25% better than NiMH and 50% better than NiCd.
- High voltage - 3.7V vs. 1.2V for NiMH.
- High drain rate – up to 2C (30 minute ) drain rate.
- Low pollution – does not contain metals like cadmium, lead, or mercury.
- Nonmetallic, high-safety – does not contain metallic Lithium.
- High cycle life - 400-500 cycles to 80% of initial capacity.
- Low self discharge.
- No memory effect.
- Fast charge rate - 80% charged in one hour and fully charged in 2.5 hours.

### 1.3 Positive Materials

- Presently contains $LiCoO_2$, which has very high energy density and stability.
- $LiMnO_2$ is being considered for very large batteries but it is not very stable with respect to degradation at high operating temperatures.
- $LiNiCoO_2$ also know as mixed oxide or super oxide, has a higher energy density than cobalt and has the potential of being less expensive. Some firms are offering this now.
- Pure LiNiO2 has not been shown to be stable in normal use, therefore it is not used. It is considered to represent the current upper limit of capacity for positive materials.

### 1.4 Negative Materials

- Graphitized spheres have the highest capacity due to easy packing and cycle life due to their strong spherical shape. They are also known as Meso Carbon Micro Beads (MCMB).

- Natural graphite has a lower capacity due to the need to add additional binders to prevent premature capacity loss when the carbon splits along the slippery graphite planes. The irregular particles are difficult to compact resulting in lower capacity per unit volume.
- The current offerings of amorphous carbons or Coke have a lower capacity.

## 2 Lithium Ion Cell Characteristics

### 2.1 Cylindrical Lithium Ion Cells

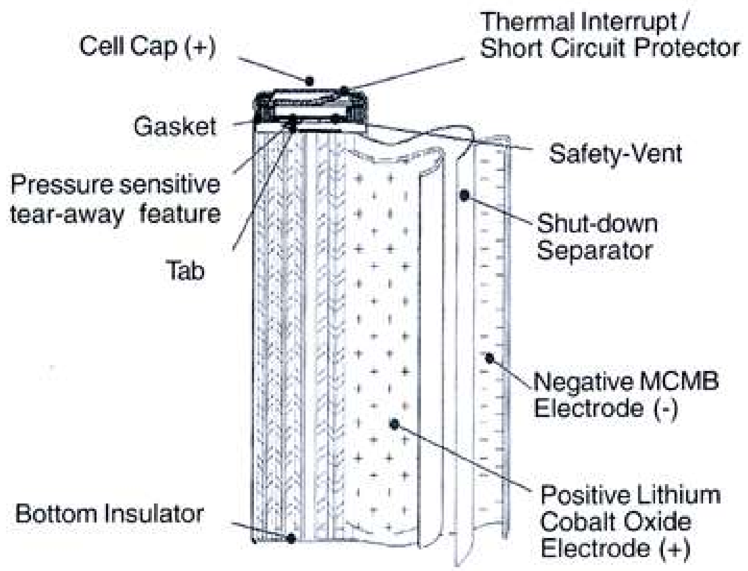
**Table 2.1**

| Model No. | Nominal Voltage | Nomial Capacity (mAH) | Charge | | Outline Dimensions | | Weight (approx. grams) |
|---|---|---|---|---|---|---|---|
| | | | Current (mA) | Time (hrs) | Diameter (mm) | Height (mm) | |
| GP17670 | 3.7 | 1350 | 810 | 2.5 | 17 | 670 | 38 |
| GP18650 | 3.7 | 1750 | 1050 | 2.5 | 18 | 650 | 44 |
| GP18500 | 3.7 | 1300 | 810 | 2.5 | 18 | 500 | 38 |

### 2.2 Cell Schematic

Figure 2.1 shows the spiral wound construction of the cylindrical cell. The positive is a coated aluminum foil and the negative is a coated copper foil. The mass free zone (MFZ) provides an area for attaching the tab. The electrodes are prevented from shorting together by a tri-layer separator. The polyethylene center closes its pores and shuts down the cell chemical reactions when the temperature exceeds 130 C. The polypropylene outer sandwich of the trilayer provides physical strength and dimensional stability at high temperatures. The conductive salt in the electrolyte is $Li^+ PF_6^-$ dissolved in a variety of solvents. The top is a structure that provides short circuit protection with a thermal device made of bimetal or Shape Memory Alloy (SMA) for protection from high temperature exposure. The safety vent prevents excessive internal pressure buildup under abusive conditions.

**Figure 2.1 Cell Schematic**

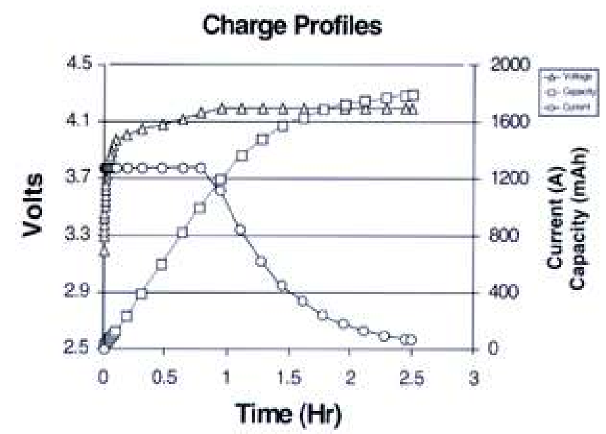



## 3 Lithium Ion Battery Performance

### 3.1 Charge Characteristics

A dedicated constant current/constant voltage battery charger is used to charge the Lithium Ion battery. The circuits are usually made with standard charger chip components that are commercially available. The cell is charged to 4.20V. The choice of the initial current allows the user to meet the initial charge maximum of 0.8C. As the cell approaches 80% of the full charge voltage of 4.20 V, the charger chip starts reducing the current to maintain constant voltage. The resulting current tends to taper off. The smaller the current, the closer the cell is to full charge. The chip allows the user to select a current corresponding to the degree of charge desired. This is usually .1 to .05 C. Review the charge curve in Figure 3.1. A supervisor circuit, also known as a safety circuit, is always provided to prevent overcharge should the charger circuit fail in the on position.

**Fig. 3.1 Charge Profiles**




### 3.2 Charge Time and Rate

As shown in Figure 3.1, the charge time is generally around 2.5 hours depending on how close to full charge is desired.

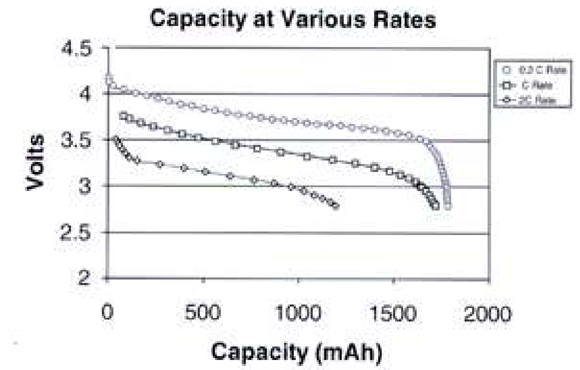
### 3.3 Charge Temperature

The taper charging takes longer at low temperatures because the current limitation starts sooner. This method brings the cell to a full charge without any additional sensors.

### 3.4 Discharge Rate Characteristics at Room Temperature

Capacity is rated at 0.2C. As shown in Figure 3.4, most of the capacity is achieved at 1C and it begins to fall off at around 2C.

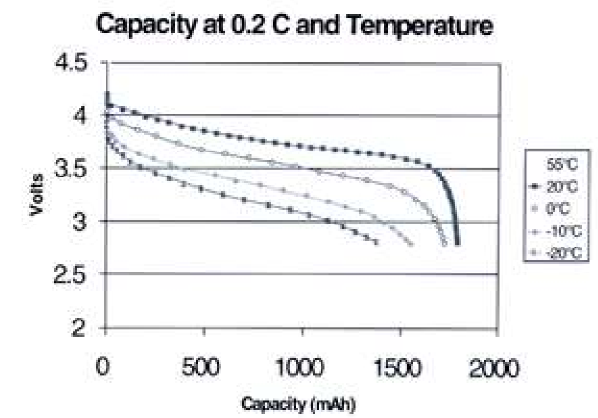
**Fig. 3.4 Capacity at Various Rates of Discharge at RT.**




### 3.5 Discharge Rate Characteristics at Low Temperatures

Figure 3.5 shows that nearly all the capacity is achieved at 20° C. There is significant loss at -20° C. This effect is aggravated at higher discharge rates.

**Fig 3.5 Capacity at 0.2 C & Temp.**

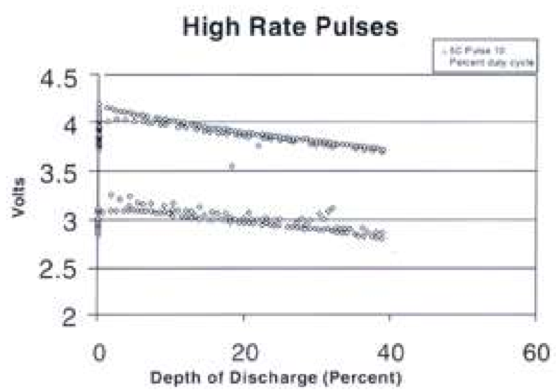


### 3.6 Pulse Discharge Mode

A large amount of the capacity of the cell to be discharged at 5 C if drawn out in short pulses.

Part of this is due to the low internal resistance of the cell current limiting device. See Figure 3.6:

**Fig. 3.6 High Rate Pulses**



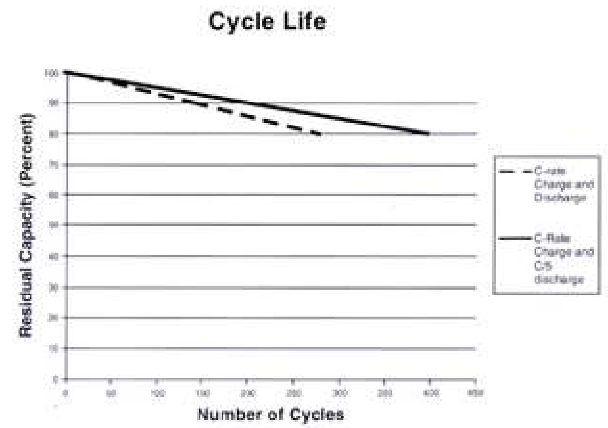

### 3.7 Cycle Life

The typical method is a C-rate charge and C-rate discharge to 100 percent depth of the discharge. This is so the calendar time to measure this characteristic is less than 6 months. This is much more strenuous than it is in actual use. For normal applications like 80% DOD and 0.2C discharge, the cycle life is typically 2-4 times longer. The time to conduct the test will be much longer than 1 year. The performance using the typical method is shown in Figure 3.7.

The result is around 300 cycles to 80% of initial capacity. Under most normal operating conditions, the life is greater than 500 cycles.

Capacity will tend to continue to fall linearly with about 70% capacity at 600 cycles.

**Fig 3.7 Cycle Life**

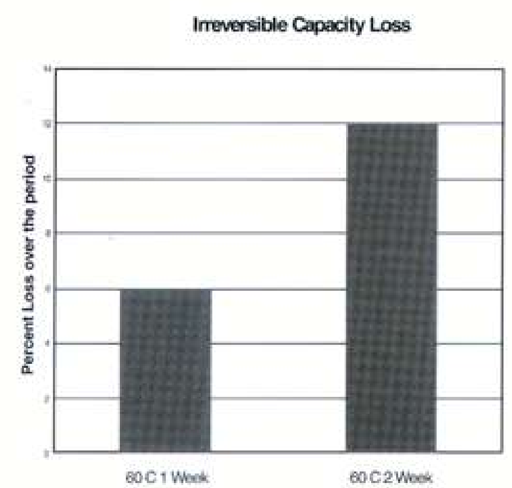



### 3.8 Self-Discharge Characteristics

There is no shuttle-based self-discharge reaction in the Lithium Ion cell like that found in the NiMH and NiCd. As the cell ages, the self-discharge eventually becomes zero. Initially the cell suffers from irreversible capacity loss. This is a reaction of the electrolyte with the active components of the cell. It occurs more rapidly with increasing temperature and cell voltage. For this reason, cells should not be stored fully charged at temperatures approaching 60°C. Optimally they should be stored at 25°C or less and between 30-50% state of charge. The lower limit is chosen because they are often stored in packs with circuitry that demands a small drain on the battery. When one considers the circuitry needed for Li-Ion, it becomes the most important source of self-discharge.

For a quick measure of the total amount of irreversible loss that a particular configuration will allow, the performance at 60°C for 1 and 2 weeks is shown in Figure 3.8:

**Fig 3.8 Irreversible Capacity Loss**




### 3.9 Performance Under Abusive Conditions

There are many tests to which cells can be subjected. The tests below are cited in the UL Standard1642. Several safety features of the cell are employed to pass these tests. These safety features include:

- Shut down separator - Melts and closes the pores of the separator if the cell warms above 130°C.
- Tear away tab - Prevents overcharge by responding to the internal cell pressure.
- Vent - When the cell is crushed or otherwise abused the cell will allow the pressure to be relieved in a controlled manner.
- Thermal Interrupt - Responds to accidental short circuit and overcharge. This is a non-resettable device when heated above the trip temperature. Lithium Ion cells can be damaged if heated above 70° C for extended periods. This device will prevent the cell from being charged if subjected to overtemperature. Other devices, like a PTC, either do not trip upon overtemperature or reset when the cell is cooled. The GP device prevents such an occurrence.

When constructed as a battery, even as a single cell battery, more devices are added to increase the likelihood that these tests can be passed with an even greater degree of confidence.

**Table 3.9 Testing Methods**

| Test | Test Method | Required Result |
|---|---|---|
| External Short Circuit | Apply a strap of 50 mohms or less. | No fire or flame. |
| Forced Discharge | At 1C dicharge, force the cell to 250% of full discharge. | No fire or flame. |
| Continuous Overcharge | Charge at 2.4C until cell temperature stabilizes. | No fire or flame. |
| Shock/ Drop/ Vibration | UL | No fire or flame. |
| Crush | Crush between flat plates to 3000 lbs. | No fire or flame. |
| Crush | Crush with a falling 20 lb. Weight, 2ft, against a 1.5 in. round bar. | No fire or flame. |
| Oven Test | Bring to 150 C for 10 minutes. | No fire or flame. |
| Projectile Test | Heat with a flame. | Debris is contained. |

### 3.10 Electrolyte Release from Abuse

If the cell is abused, it is possible for a small amount of electrolyte to be released through the cell vent. There are no toxic or poisonous substances released from the vent. Most of the electrolyte will be withheld by the very small pores of the electrodes and the separator. The mixture of the solvents used is organic in nature and will burn if a flame is applied. The salt $LiPF_6$ is not stable with respect to water and will decompose to make small amounts of skin irritants. The best way to prevent skin irritation and inflammation is to wash with large amounts of water.

## 4 Battery Packs

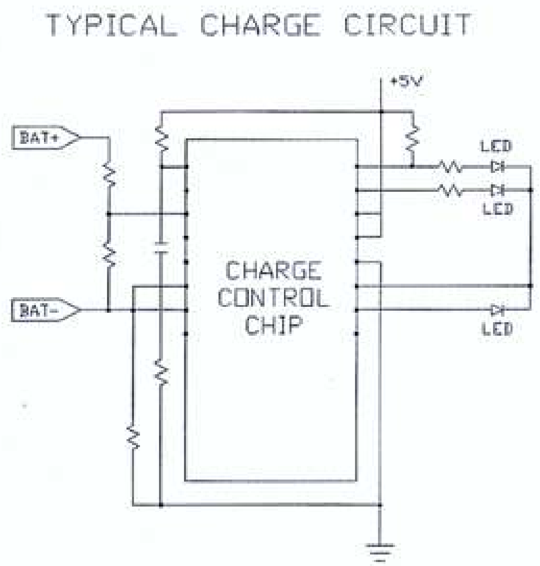
A battery pack is a cell or many cells that are connected in series and parallel configurations that are charged with chargers specifically designed for Lithium Ion Battery Packs. They contain several safety features that are electronic in nature. Recently, this also includes a means for making calculations, displaying information, and communicating with digital devices like computers, giving them the name Smart Packs.

### 4.1 Charging Circuit

- The charger is typically external to the Battery Pack.
- Charging Constant current mode must be adjustable from to 0.8C or less.
- Taper Charge mode must be adjustable to shut off from 0.05C to 0.1C.
- The charge circuit must charge the cell to 4.20 +/- 0.05V.

See Figure 4.1 for a typical charger circuit:

**Figure 4.1 Typical Charge Circuit**




### 4.2 Smart Chargers

There are three levels of smart chargers:

- Level 1 charger can receive a signal from a smart battery to start or stop charging.
- Level 2 charger can receive instructions from smart battery and act to control voltage and current in response to requests by the battery.
- Level 3 charger can request information from the battery in addition to being a passive listener like a Level 2 charger.

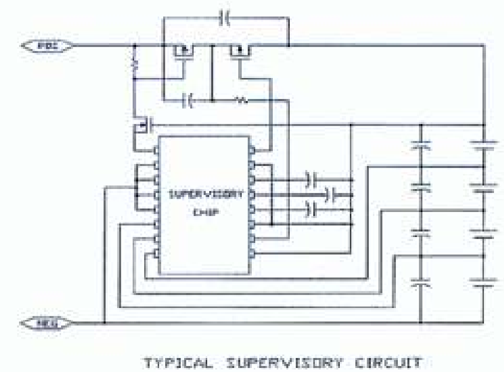
We use chip sets that use the SMBus protocol which is a battery specific implementation of $I^2C$.

### 4.3 Safety Circuit

- The safety circuit is typically part of the battery pack.
- The additional safety chip and circuit must terminate charge at 4.25 +/- .05V.
- The additional safety chip and circuit must terminate discharge below 2.8.
- The additional safety chip must detect an external short circuit and prohibit discharge of the battery.
- The additional safety chip must be provided for each cell or string of cells connected in series.

See Figure 4.3 for a typical safety circuit for a 2,3,4 cell in series combination.

**Figure 4.3 Typical Supervisory Circuit**




### 4.4 Other Devices

Depending on the application, it may be desirable to add additional thermal detection and protection. See Table 4.4:

**Table 4.4 Thermistor Functions**

| Sensor | Function | Temperature |
|---|---|---|
| Thermistor | Detection of Battery Temperature | 0-55 C |
| PTC switch | Switch at high current and temperature with reset | 90-98 C |
| Temperature Fuse | Switch at high temperature with no reset | 90-98 C |

A fuel gage chip can be added to the pack to light LED's on the pack to indicate the packs capacity or to communicate with a digital device.

### 4.5 Smart Packs

**Smart Packs**

In addition to a gas gauge and limited communication capability, the smart pack provides a range of other services.

This pack is provided with a smart chip that can communicate using SMBus.

SMBus is a battery specific implemenation of the $I^2C$ hardware standard. These standards enable manufacturers to develop the end use, chargers, and packs independently. Level 2 means that the charger is under the direction of the SMBus pack. Level 3 means the charger can request from the pack various services. The main one being the way the pack prefers to be charged.

Accuracy of the state of charge has been improved. Timers, charge measurement, and temperature sensors can be combined with algorithms inside the chip to correct the amount of charge going in and out of the pack with respect to these variables. Lithium Ion chemistry operates with 100% coulombic efficiency. This means that, unlike NiMH and NiCd, the amount of charge acceptance is independent of the temperature and state of charge. Lithium Ion is a "what-you-measure is correct" type of system. Accuracy is improved by correcting the available run time with the discharge rate. As noted before the available run time begins to decrease at discharge rates above 1.5C. If one operates with discharge rates closer to 1C or less, the improvement in accuracy using a smart pack is minimal.

Smart packs have a variety of memory registers that can report their state to the application via the SMBus. Such information includes (among others):

- Residual Capacity
- Charge Control
- Charge/Discharge Cycle Record
- Voltage Record
- Current Record
- Temperature Record

# 5 Design, Construction, Shipping and Handling of Packs

## 5.1 Handling Precautions

### Table 5.1 Handling Precautions

| | |
|---|---|
| **Charge** | |
| Charge Voltage | Charge to 4.20 +/- .05 V per cell, each being supervised. |
| Charge Current | Do not exceed .8 C. |
| Charge Temperature | Charge in the range of 0 to 45oC. |
| **Discharge** | |
| Discharge Current | Size the discharge control elements to be able to take the maximum current. |
| Discharge Temperature | Discharge in the range of -20 to 60oC. |
| Over Discharge | Do not discharge below 2.8 V/cell under significant loads. Small leakage currents may discharge the cell further. Do not discharge below 2.OV/cell or damage to the cell can occur. |
| **Storage** | |
| Storage Temperature | Store at -20 to 35oC. Significant permanent loss can occur when storing at 60oC. Keep the battery away from fire. |
| Long Term Storage | Deterioration of cell capacity is slower at lower states of charge. Store at below 50% state of charge or about 3.7V/cell. If storing for more than one year, recharge the battery to 3.7V/cell to prevent overdischarge of the battery. |
| **Equipment Design** | |
| Reverse Polarity Prevention | Provide mechanical stops so the the pack cannot be inserted in a reverse manner. The electrical contacts should be designed so that they are difficult to short. |
| Electronic Circuit Location | Elements like solid state safety circuits should be mounted so that the are not subjected to high temperature or electromagnetic fields emanating from the device it is powering or being charged by. If possible, the electronic circuit should be isolated from the cells to avoid a malfunction caused by electrolyte leakage. |
| Damage Prevention due to drop | The pack wiring and cells should be protected inside the pack by designing the pack to absorb shock due to drop and vibrations. |

## 5.1 Customer Application Form

### Table 5.2 Customer Application Form - Page 1

GOLD PEAK

CUSTOMER APPLICATION FORM
FOR
NEW LI-ION PRODUCT DEVELOPMENT
SHEET 1 OF 2

CAP#
CUSTOMER: ____
SALESPERSON: ____
SALES ORDER #: ____
DATE:

We sincerely appreciate your interest in GP Batteries. This application form will enable our engineers to properly determine the best battery design to meet your needs. Please fill out this form as completely as possible. We will be happy to provide you with samples, testing or our recommendations and work with you on a final design.

I. CUSTOMER: ____
ADDRESS: ____ CITY: ____
STATE: ____ ZIP: ____
CONTACT NAME: ____ TITLE: ____
PHONE: ____ FAX: ____ E-mail: ____

II. PRODUCT DEFINITION:
A. DESCRIPTION: ____ CELL TYPE (circle one): 17670 / 18650
☐ DR201 ☐ DR202

B. APPLICATION: ☐ SOFT PACK ☐ PLASTIC CASE ☐ OTHER ____
CONFIGURATION: ____ SERIES ____ PARALLEL
PACK VOLTAGE: ____ VOLTS

C. TYPE REQUEST: ☐ SAMPLES ☐ QUOTE ☐ TESTING QUANTITY /YEAR: ____

D. TYPE DESIGN: ☐ PRELIMINARY ☐ MECHANICAL ONLY ☐ ELECTRICAL ONLY ☐ FINAL

E. SHIP TO: ☐ SAME AS ABOVE ☐ SALESPERSON
REQUIRED DATE AT CUSTOMER:
☐ NAME: ____ COMPANY: ____
ADDRESS: ____
CITY: ____ STATE: ____ ZIP: ____

F. SPECIFICATIONS: ☐ CUSTOMER DRAWING ☐ CUSTOMER SAMPLE (S)
DWG# ____ REV. ____
☐ WRITTEN SPEC. TITLE: ____ DATE: ____
☐ OTHER - DEFINE ____

SKETCH REQUIRED SAMPLES:

AS REQUIRED: ____

1. SHOW ALL CRITICAL DIMENSIONS WITH TOLERANCES OR MAX.
2. SHOW CONNECTOR POLARITY.
3. SHOW LABEL ORIENTATION.
4. SHOW AND LIST ANY SPECIAL FEATURES OR MATERIALS.

G. PROTECTION/ SAFETY: ALL SAMPLES ARE SHIPPED WITH SAFETY CIRCUITS TO PROTECT AGAINST OVERCHARGING, OVER DISCHARGING AND SHORT CIRCUITS.

H. CHARGING REQUIREMENTS:
Charging of lithium ion cells must be controlled by an acceptable battery supervisor control chip.
If you are not using a GP approved commercial Li Ion charger, GP would like to review and approve your charger circuit.

CONTROLLER CHIP MANUFACTURER: ____ MODEL # ____
CHARGER MANUFACTURER: ____ MODEL # ____

TEMPERATURE RANGE: ____ Deg C to ____ Deg C
( If the temperature can go outside the acceptable GP range, a themistor should be used to prevent charge. )

**Table 5.3 Customer Application Form - Page 2**

| GOLD PEAK | CUSTOMER APPLICATION FORM<br>FOR<br>NEW LI-ION PRODUCT DEVELOPMENT | CAP #<br>SHEET 2 OF 2 |
|---|---|---|

I. CHARGING PARAMETERS:

| CHARGE MODE | CHARGE | | | | |
|---|---|---|---|---|---|
| FOR LITHIUM ION | CURRENT TO VOLTAGE LIMIT (mA) | VOLTAGE LIMIT (V) (<4.2V/CELL) | TIME (hrs.) | TAPER CURRENT | |
| RECOMMENDED | .8C | 4.2 | 2.5 | C/20 | |
| CUSTOMER'S PROPOSED | | | | | |

THE METHOD OF CHARGING AND DISCHARGING A LITHIUM ION BATTERY IS VERY IMPORTANT TO THE SAFETY AND PERFORMANCE OF THE BATTERY.

CONSULT GP ENGINEERING FOR OPTIMUM SAFETY AND PERFORMANCE.

J. DISCHARGE PARAMETERS:

PLEASE DESCRIBE OR SKETCH DISCHARGE CURRENT PROFILE BELOW:

MAXIMUM CONTINUOUS CURRENT = 2.4A / SERIES CELL ( HIGHER PULSE DISCHARGE RATES MAY BE ACCEPTABLE).

DISCHARGE TERMINATION METHOD:

VOLTAGE < 2.8 VOLTS / SERIES CELL

OPERATING TEMPERATURE:

| | MINIMUM | MAXIMUM |
|---|---|---|
| RECOMMENDED | | |
| IN DISCHARGE | | |
| | | |

K. SMART BATTERY REQUIREMENTS:

☐ SMBus COMMUNICATION WITH BENCHMARQ Bq2040/ Bq2060 CHIP

☐ FUEL GAUGE ON BATTERY PACK

L. OTHER COMMENTS:

GP USE ONLY

APPROVALS:

SALES: ________ ENGINEERING: ________

## Notes

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# Lithium Ion

## technical handbook




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