Lithium Ion Catalog

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 LiCoO2 is listed below. See schematic in Figure 2.1.

Table 1.1 Charge Discharge Reaction

<table>
<thead>
<tr>
<th>Charge</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>LiCoO2 - e^-</td>
<td>Li^+ 1+</td>
<td>CoO2^-2</td>
</tr>
<tr>
<td>LiCoO2 + e^-</td>
<td>Li^+ 1+</td>
<td>CoO2^-2</td>
</tr>
<tr>
<td>Overall</td>
<td>LiCoO2</td>
<td>Li + CoO2</td>
</tr>
</tbody>
</table>

1.2 General Features

- High energy density - greater than 300 Wh/kl and 150 Wh/kg; about 25% better than NiMH and 50% better than NiCd.
- High voltage - 3.7V vs. 1.2V for NiMH.

1.3 Positive Materials

- Presently contains LiCoO2, which has very high energy density and stability.
- LiMn2O4 is being considered for very large batteries. It is not stable with respect to degradation at high operating temperatures.
- LiNiCoO2, also known 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 Mesocarbon Micro Beads (MCMB).
2 Lithium Ion Cell Characteristics

2.1 Cylindrical Lithium Ion Cells

Table 2.1

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Nominal Voltage (V)</th>
<th>Nominal Capacity (mAh)</th>
<th>Charge Rate</th>
<th>Discharge Rate</th>
<th>Dimensions (mm)</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GP991-105</td>
<td>3.7</td>
<td>1350</td>
<td>940</td>
<td>2.5</td>
<td>17</td>
<td>375</td>
</tr>
<tr>
<td>GP995-100</td>
<td>3.7</td>
<td>1750</td>
<td>1000</td>
<td>2.3</td>
<td>18</td>
<td>400</td>
</tr>
<tr>
<td>GP996-100</td>
<td>3.7</td>
<td>1700</td>
<td>1000</td>
<td>2.3</td>
<td>18</td>
<td>400</td>
</tr>
</tbody>
</table>

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 4.2V. 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 4.20V, 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 0.5C. 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 to turn on.

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.

3.5 Discharge Rate Characteristics at Low Temperatures

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

Fig 3.5 Capacity at 0.2C & 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](image)

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 that measured 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](image)

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](image)

3.9 Performance Under Abusive Conditions

There are many tests to which cells can be subjected. The tests below are cited in the UL Standard 1642.

Several safety features of the cell are employed to pass these tests. These safety features include:

- **Thermal Intermitt**: 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

<table>
<thead>
<tr>
<th>Test</th>
<th>Test Method</th>
<th>Required Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Short Circuit</td>
<td>Apply a step of 50 milliamps or less.</td>
<td>No fire or flame.</td>
</tr>
<tr>
<td>Forced Discharge</td>
<td>At 10 discharge, force the cell to 200% of full discharge.</td>
<td>No fire or flame.</td>
</tr>
<tr>
<td>Continuous Overcharge</td>
<td>Charge at 2.4.3 until cell temperature stabilizes.</td>
<td>No fire or flame.</td>
</tr>
<tr>
<td>Shock/Drop/Vibration</td>
<td>LL.</td>
<td>No fire or flame.</td>
</tr>
<tr>
<td>Crush</td>
<td>Crush between flat plates to 3000 lbs.</td>
<td>No fire or flame.</td>
</tr>
<tr>
<td>Crush</td>
<td>Crush with a testing 20 lb. weight, 2 ft. against a 1.5 in. round bolt.</td>
<td>No fire or flame.</td>
</tr>
<tr>
<td>Oven Test</td>
<td>Bring to 160°C for 16 minutes.</td>
<td>No fire or flame.</td>
</tr>
<tr>
<td>Projectile Test</td>
<td>Heat with a flame.</td>
<td>Debris is contained</td>
</tr>
</tbody>
</table>
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 maxing calculations, display 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 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](image)

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.

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](image)

4.4 Other Devices

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

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Function</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermistor</td>
<td>Detection of Battery temperature</td>
<td>0-05 C</td>
</tr>
<tr>
<td>PTC switch</td>
<td>Switch at high current and temperature with resist</td>
<td>90-96 C</td>
</tr>
<tr>
<td>Temperature Fuse</td>
<td>Switch at high temperature with no resist</td>
<td>90-96 C</td>
</tr>
</tbody>
</table>

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 implementation of the I²C hardware standard. These standards enable manufacturers to develop 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

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Charge</strong></td>
<td></td>
</tr>
<tr>
<td>Charge Voltage</td>
<td>Charge to 4.20 +/- .05 V per cell, each being supervised.</td>
</tr>
<tr>
<td>Charge Current</td>
<td>Do not exceed 8 C.</td>
</tr>
<tr>
<td>Charge Temperature</td>
<td>Charge in the range of 0 to 45°C.</td>
</tr>
<tr>
<td><strong>Discharge</strong></td>
<td></td>
</tr>
<tr>
<td>Discharge Current</td>
<td>Size the discharge control elements to be able to take the maximum current.</td>
</tr>
<tr>
<td>Discharge Temperature</td>
<td>Discharge in the range of -20 to 60°C.</td>
</tr>
<tr>
<td>Over Discharge</td>
<td>Do not discharge below 2.8 V/cell under significant loads. Small leakage currents may discharge the cell further. Do not discharge below 2.0 V/cell or damage to the cell can occur.</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>Store at -20 to 350°C; Significant permanent loss can occur when storing at 50°C. Keep the battery away from fire.</td>
</tr>
<tr>
<td>Long Term Storage</td>
<td>Deterioration of cell capacity is slower at lower states of charge. Store at below 50% state of charge or about 3.7 V/cell. If storing for more than one year, recharge the battery to 3.7 V/cell to prevent overdischarge of the battery.</td>
</tr>
<tr>
<td>Equipment Design</td>
<td></td>
</tr>
<tr>
<td>Reverse Polarity</td>
<td>Provide mechanical stops so the pack cannot be inserted in a reverse manner. The electrical contacts should be designed so that they are difficult to short.</td>
</tr>
<tr>
<td>Prevention</td>
<td></td>
</tr>
<tr>
<td>Electronic Circuit</td>
<td>Elements like solid state safety circuits should be mounted so that the area is 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.</td>
</tr>
<tr>
<td>Location</td>
<td></td>
</tr>
<tr>
<td>Damage Prevention due</td>
<td>The pack wiring and cells should be protected inside the pack by designing the pack to absorb shock due to drop and vibrations.</td>
</tr>
</tbody>
</table>

5.1 Customer Application Form

Table 5.2 Customer Application Form - Page 1

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.

<table>
<thead>
<tr>
<th>CUSTOMER</th>
<th>ADDRESS</th>
<th>STATE</th>
<th>CITY</th>
<th>ZIP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PRODUCT TYPE</th>
<th></th>
<th>SHOP NAME</th>
<th>SALES ORDER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DEPART.</td>
<td></td>
</tr>
</tbody>
</table>

We appreciate your attention to the technical data and specifications provided in this document. If you have any questions or require further information, please feel free to contact us at your convenience.

C. PROTECTION: All sample ships with protective circuitry to protect against overcharging, over-discharging, short circuits, and any other problems.

D. CHARGING REQUIREMENTS:
- The battery must be charged using a compatible charger.
- Ensure proper voltage and current settings as specified by the manufacturer.
- Do not exceed the maximum allowed voltage and current settings.

E. REGISTRATION:
- All users should register their batteries with the manufacturer for future reference and support.
- The registration process is quick and easy, and can be completed online or by mail.

F. WARRANTY:
- The battery is covered by a limited warranty for a period of one year from the date of purchase.
- The warranty covers any defects in materials and workmanship.

G. DISCLAIMER:
- The information provided in this document is intended for educational purposes only.
- GP Batteries makes no warranties, express or implied, regarding the accuracy or completeness of this information.
- GP Batteries disclaims any liability for damages or losses incurred as a result of using the information provided in this document.

H. DISCLAIMER:
- GP Batteries reserves the right to change the specifications and design of its products without notice.
- The user is responsible for ensuring that the product meets the intended application.

I. DISCLAIMER:
- GP Batteries is not responsible for any accidents or incidents that may occur due to the use of its products.
- The user is responsible for ensuring that the product is used safely and appropriately.

J. DISCLAIMER:
- The user is responsible for ensuring that the product is used in accordance with all applicable laws and regulations.
- GP Batteries is not responsible for any legal consequences that may arise as a result of the use of its products.

K. DISCLAIMER:
- The user is responsible for ensuring that the product is used in accordance with the manufacturer's instructions.
- GP Batteries is not responsible for any losses or damages that may occur as a result of the user's failure to follow the instructions.

L. DISCLAIMER:
- The user is responsible for ensuring that the product is used in accordance with the user's own risk and judgment.
- GP Batteries is not responsible for any losses or damages that may occur as a result of the user's failure to use the product safely.

M. DISCLAIMER:
- The user is responsible for ensuring that the product is used in accordance with the manufacturer's guidelines and recommendations.
- GP Batteries is not responsible for any losses or damages that may occur as a result of the user's failure to follow the guidelines.

N. DISCLAIMER:
- The user is responsible for ensuring that the product is used in accordance with the user's own experience and knowledge.
- GP Batteries is not responsible for any losses or damages that may occur as a result of the user's failure to use the product safely.

O. DISCLAIMER:
- The user is responsible for ensuring that the product is used in accordance with the manufacturer's recommendations and guidelines.
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P. DISCLAIMER:
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T. DISCLAIMER:
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U. DISCLAIMER:
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V. DISCLAIMER:
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X. DISCLAIMER:
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Y. DISCLAIMER:
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Z. DISCLAIMER:
- The user is responsible for ensuring that the product is used in accordance with the manufacturer's instructions and guidelines.
- GP Batteries is not responsible for any losses or damages that may occur as a result of the user's failure to follow the instructions.
### Table 5.3 Customer Application Form - Page 2

#### Notes

**1. Charging Parameters:**

<table>
<thead>
<tr>
<th>Charge Mode</th>
<th>Current Limit (A)</th>
<th>Voltage Limit (V)</th>
<th>Time (h)</th>
<th>Taper Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>For Lithium Ion</td>
<td>6C</td>
<td>4.2</td>
<td>2.5</td>
<td>C/20</td>
</tr>
</tbody>
</table>

**Recommended**

**Customers Proposed**

The method of charging and discharging a lithium ion battery is very important to the safety and performance of the battery. Consult OP Engineering for optimum safety and performance.

**2. 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 < 2.0 Volts / SERIES CELL

**Operating Temperature:**

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
</table>

**Recommended**

**3. Smart Battery Requirements:**

- SMBus Communication with BENCHMARK bC0300 bC0600 CRP
- Full Gauge on Battery Pack

**4. Other Comments:**

- Approval:
  - Sales
  - Engineering
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