Rechargeable batteries play an important role in our life and many daily chores would be unthinkable without the ability to recharge an empty battery. Points of interest are specific energy, years of service life, load characteristics, safety, price, self-discharge, environmental issues, maintenance requirements, and disposal.

**Lead Acid** — One of the oldest rechargeable battery systems; is rugged, forgiving if abused and economical in price; has a low specific energy and limited cycle life. Lead acid is used for wheelchairs, golf cars, personnel carriers, emergency lighting and uninterruptible power supply (UPS).

**Nickel-cadmium (NiCd)** — Mature and well understood; is used where long service life, high discharge current, extreme temperatures and economical price are of importance. Due to environmental concerns, NiCd is being replaced with other chemistries. Main applications are power tools, two-way radios, aircraft and UPS.

**Nickel-metal-hydride (NiMH)** — A practical replacement for NiCd; has higher specific energy with fewer toxic metals. NiMH is used for medical instruments, hybrid cars and industrial applications. NiMH is available in AA and AAA cells for consumer use.

**Lithium-ion (Li-ion)** — Most promising battery systems; is used for portable consumer products as well as electric powertrains for vehicles; is more expensive than nickel- and lead acid systems and needs protection circuit for safety.

The lithium-ion family is divided into three major battery types, so named by their cathode oxides, which are cobalt, manganese and phosphate. The characteristics of these Li-ion systems are as follows.

**Lithium-ion-cobalt or lithium-cobalt (LiCoO2):** Has high specific energy with moderate load capabilities and modest service life. Applications include cell phones, laptops, digital cameras and wearable products.

**Lithium-ion-manganese or lithium-manganese (LiMn2O4):** Is capable of high charge and discharge currents but has low specific energy and modest service life; used for power tools, medical instruments and electric powertrains.

**Lithium-ion-phosphate or lithium-phosphate (LiFePO4):** Is similar to lithium-manganese; nominal voltage is 3.3V/cell; offers long cycle life, has a good safe record but exhibits higher self-discharge than other Li-ion systems.

There are many other lithium-ion based batteries, some of which are described further on this website. Missing in the list is also the popular lithium-ion-polymer, or Li-polymer. While Li-ion systems get their name from their unique cathode materials, Li-polymer differs by having a distinct architecture. Nor is the rechargeable lithium-metal mentioned. This battery requires further development to control dendrite growth, which can compromise safety. Once solved, Li-metal will become an alternative battery choice with extraordinary high specific energy and good specific power.

Table 1 compares the characteristics of four commonly used rechargeable battery systems showing average performance ratings at time of publication.
Table 1: Characteristics of commonly used rechargeable batteries

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Lead Acid</th>
<th>NiCd</th>
<th>NiMH</th>
<th>Li-ion Cobalt</th>
<th>Li-ion Manganese</th>
<th>Li-ion Phosphate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific energy density (Wh/kg)</td>
<td>30–50</td>
<td>45–60</td>
<td>60–120</td>
<td>150–190</td>
<td>100–135</td>
<td>90–120</td>
</tr>
<tr>
<td>Internal resistance (mΩ)</td>
<td>&lt;100</td>
<td>100–200</td>
<td>200–300</td>
<td>150–300</td>
<td>25–75 per cell</td>
<td>25–50 per cell</td>
</tr>
<tr>
<td>Cycle life (80% discharge)</td>
<td>200–300</td>
<td>1000³</td>
<td>300–500²</td>
<td>500–1,000</td>
<td>500–1,000</td>
<td>1,000–2,000</td>
</tr>
<tr>
<td>Fast-charge time</td>
<td>8–16 h</td>
<td>1 h typical</td>
<td>2–4 h</td>
<td>2–4 h</td>
<td>1 h or less</td>
<td>1 h or less</td>
</tr>
<tr>
<td>Overcharge tolerance</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>Low. Cannot tolerate trickle charge</td>
<td></td>
</tr>
<tr>
<td>Self-discharge/month (room temp)</td>
<td>5%</td>
<td>20%⁵</td>
<td>30%⁵</td>
<td>&lt;10%⁶</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell voltage (nominal)</td>
<td>2 V</td>
<td>1.2 V⁷</td>
<td>1.2 V⁷</td>
<td>3.6 V⁸</td>
<td>3.6 V⁸</td>
<td>3.3 V</td>
</tr>
<tr>
<td>Charge cutoff voltage (V/cell)</td>
<td>2.40</td>
<td>Full charge by voltage detection</td>
<td>4.20</td>
<td>3.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discharge cutoff voltage (V/cell, 1C)</td>
<td>1.75</td>
<td>1.00</td>
<td>2.50–3.00</td>
<td>2.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak load current (Best result)</td>
<td>5C⁹</td>
<td>20C⁹</td>
<td>5C⁹</td>
<td>&gt;3C</td>
<td>&gt;30C</td>
<td>&gt;30C</td>
</tr>
<tr>
<td>Charge temperature</td>
<td>-20 to 50°C</td>
<td>0 to 45°C</td>
<td>0 to 45°C¹⁰</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discharge temperature</td>
<td>-20 to 50°C</td>
<td>-20 to 65°C</td>
<td>-20 to 50°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance requirement</td>
<td>3–6 months¹¹ (topping charge)</td>
<td>30–60 days (discharge)</td>
<td>60–90 days (discharge)</td>
<td>Not required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety requirements</td>
<td>Thermally stable</td>
<td>Thermally stable, fuse protection common</td>
<td>Protection circuit mandatory¹²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In use since</td>
<td>Late 1800s</td>
<td>1950</td>
<td>1990</td>
<td>1991</td>
<td>1995</td>
<td>1999</td>
</tr>
</tbody>
</table>

Table 1: Characteristics of commonly used rechargeable batteries

The figures are based on average ratings of commercial batteries at time of publication; experimental batteries with above-average ratings are excluded.

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1. Internal resistance of a battery pack varies with milliampere-hour (mAh) rating, wiring and number of cells. Protection circuit of lithium-ion adds about 100mΩ.
2. Based on 18650 cell size. Cell size and design determines internal resistance.
3. Cycle life is based on battery receiving regular maintenance.
4. Cycle life is based on the depth of discharge (DoD). Shallow DoD improves cycle life.
5. Self-discharge is highest immediately after charge. NiCd loses 10% in the first 24 hours, then declines to 10% every 30 days. High temperature increases self-discharge.
6. Internal protection circuits typically consume 3% of the stored energy per month.
7. The traditional voltage is 1.25V; 1.2V is more commonly used.
8. Low internal resistance reduces the voltage drop under load and Li-ion is often rated higher than 3.6V/cell. Cells marked 3.7V and 3.8V are fully compatible with 3.6V.
9. Capable of high current pulses; needs time to recuperate.
10. Do not charge regular Li-ion below freezing. See Charging at High and Low Temperatures.
11. Maintenance may be in the form of equalizing or topping charge to prevent sulfation.
12. Cut-off if less than 2.20V or more than 4.30V for most Li-ion; different voltage settings apply for lithium-iron-phosphate.

*** Please Read Regarding Comments ***

Comments are intended for "commenting," an open discussion amongst site visitors. Battery University monitors the comments and understands the importance of expressing perspectives and opinions in a shared forum. However, all communication must be done with the use of appropriate language and the avoidance of spam and discrimination.
If you have a question, require further information, have a suggestion or would like to report an error, use the “contact us” form or email us at: answers@cadex.com. While we make all efforts to answer your questions accurately, we cannot guarantee results. Neither can we take responsibility for any damages or injuries that may result as a consequence of the information provided. Please accept our advice as a free public support rather than an engineering or professional service.

Comments

On March 24, 2011 at 8:32am
Le Van Nam wrote:
I need to know the temperature at which lead is broken to become powder. Can you help me? Thank you very much.

On November 2, 2011 at 7:15pm
betterpower battery wrote:
I learned much.

On December 19, 2011 at 12:17pm
Tom Marshall wrote:
I was reading elsewhere about Lithium Iron (sic) Phosphate (or LiFePO4) batteries becoming the ideal replacement for traditional 12V deep cell lead acid batteries commonly used for camping purposes to power small compressor fridges and the like, and in recreational vehicles as a power source when stationary where no mains power is available. Have you more information on these?

On April 27, 2012 at 1:02am
Hossein wrote:
thanks a lot.

On June 13, 2012 at 3:11pm
battery guy wrote:
Classifying Li-ion as “maintenance not required” seems to be misunderstood outside the battery industry. Working in the battery industry for the past 5 years I have found that it’s a common misconception of battery users that a Li-ion battery can sit on a shelf or installed in a device for nearly indefinite periods of time without recharging (of course not true of any chemistry). If a lithium battery is left to self discharge to 0% SOC and remains in storage allowing the protection circuit to further deplete the cells, this often results in a damaged or unusable battery (unhappy customer).

This site is excellent! Keep it up.

On September 26, 2012 at 6:29am
Dr wrote:
Please tell me if Li Ion battery has what is called “memory effect” which means it has to be fully discharged before charging again? In other words, can it be charged as often as we want, like in between the usage so that battery charge does not go off during the use of the equipment? PLEASE MAIL TO drsajeevk@gmail.com

Sincerely,
Dr.Sajeev Kumar

On January 15, 2013 at 7:35pm
roy wrote:
Following rows if added shall make the table great:
-Electrolyte
-Gases produced, if any
-Weight to Capacity ratio

On March 23, 2013 at 1:29am
bill mc allister wrote:
If I connected multiple super capacitors to replace a 12 volt car battery in sequence, could I achieve enough power to start my engine, if so how many and what size capacitor. Please email any info that can assist me to billyjoe68@live.ca thank you so much for this web page.
On May 2, 2013 at 2:53pm

Mads wrote:

The description is pretty good. I think it would be really worth to add a little bit of today’s so popular lithium-polymer (LiPo) and mention also chemistries like lithium-sulphur (LiS) and lithium-air as well.

On May 30, 2013 at 1:10pm

Don wrote:

Note in reading this page I have noticed that there seems to be an error in your temperature values in Table 1 - Discharge temperature, Column 1 is -20°C to 50°C and -4°F to ?°F (note ? mark for missing data). Column 2 is -20 to 65°C and -4 to 49°F, column 3/4/5 is -20 to 60°C and -4 to 140°F. How can the values of 65°C and 60°C convert respectively to 49°F and 140°F?

Thanks

On July 19, 2013 at 10:50pm

Henry wrote:

Excellent site—much needed info, well presented.

In note 1 of Table 1, where it says “Protection circuit of lithium-ion adds about 100mW.”, did you mean to say 100mΩ?

On July 22, 2013 at 8:41am

Cadex Electronics Inc. wrote:

Yes, thank you Henry. I have made the correction.

On September 23, 2013 at 10:11pm

neha wrote:

Is there any battery/fuel cell or any other power source which does not discharge by itself when left unused for months? It should be compact and able to supply at least 5V of energy.

On November 14, 2013 at 3:14am

Dave wrote:

What about Nickel Iron batteries (Knife Cells) ??

I believe they used to be used for low internal resistance applications but were unpopular because of the Potassium Hydroxide electrolyte.

On November 14, 2013 at 3:41am

neha wrote:

thanks for the info

On December 15, 2013 at 12:51am

muhammad wrote:

compare the 5 rating used in the battery rating

On December 21, 2013 at 9:43am

Bante wrote:

There used to be a type of Lithium Ion cell with a charge cutoff at 4.1V; I think the nominal voltage was 3.5V. What type of cell would this be? I have searched many sites but could not find any reference to it.

All these pages are very good indeed, but an update would be very welcome!

On December 25, 2013 at 3:01am

Not an EE wrote:

Typo in Note 1 above, which says “Protection circuit of lithium-ion adds about 100mW.” Should read 100m (omega symbol); ohms, not watts.
On March 23, 2014 at 11:49am
Mohammad Abbas wrote:

we want to make a small battery assembly unit and join them with nikel tabs together and wrap them in shrink tubing with different sorts of connectors for biomedical equipment use and communication equipment use, please advise by email your recommended spot welder for nicle tabs and some shrink tubing manufacturer as well as other battery manufacturers of bare cells of regular and lithiumion cells. in a nutshell to make custom battery packs and advise us on the machinery and equipment required.

On April 4, 2014 at 9:25am

Onceuponatimebatteryengineer wrote:

Great source of information. I am just not clear what rate capability (not specified here) is. For example, the peak load current and best result range of Lithium ion battery chemistries is vastly superior to other types. Does that mean that the rate capability of Li-ion batteries is superior? Also, within the Li-ion group, the cobalt system is different from Manganese and Phosphate. Does that mean that the phosphates are superior to cobalt system of Li-ion batteries when it comes to “Rate Capability”.

On August 12, 2014 at 6:32am

Saluti wrote:

Could you give me an comparison of Efficiency on LiNCM vs. LFP?
at different current rates:
20-hr
4-hr
2-hr
1-hr

thx vm iadvce

On November 9, 2014 at 12:35pm

Smb wrote:

I see 18650 batteries with, for example, 30amp continuous discharge and 60amp pulse discharge. My question is this: how long is a pulse then. Meaning how long Does the battery have to be active before going from pulse to continuous?

Thanks.

On March 6, 2015 at 11:07am

Greg Lander wrote:

Question: How long to re-charge a 500 kW, 2,500 kWh Li-ion (Manganese or Phospbate) from 80% discharge to 90% charge from a 100 kW generator?