Battery University

BU-107: Comparison Table of Secondary Batteries

Select between maximum runtime, long service life, small size and low cost.

Rechargeable batteries play an important role in our lives and many daily chores would be unthinkable without the ability to recharge. The most common rechargeable batteries are lead acid, NiCd, NiMH and Li-ion. Here is a brief summary of their characteristics.

- Lead Acid – This is the oldest rechargeable battery system. Lead acid is rugged, forgiving if abused and is economically priced, but it has a low specific energy and limited cycle count. Lead acid is used for wheelchairs, golf cars, personnel carriers, emergency lighting and uninterruptible power supply (UPS). Lead is toxic and cannot be disposed in landfills.

- Nickel-cadmium – Mature and well understood, NiCd is used where long service life, high discharge current and extreme temperatures are required. NiCd is one of the most rugged and enduring batteries; it is the only chemistry that allows ultra-fast charging with minimal stress. Main applications are power tools, medical devices, aviation and UPS. Due to environmental concerns, NiCd is being replaced with other chemistries, but it retains its status in aircraft due to its good safety record.

- Nickel-metal-hydride – Serves as a replacement for NiCd as it has only mild toxic metals and provides higher specific energy. NiMH is used for medical instruments, hybrid cars and industrial applications. NiMH is also available in AA and AAA cells for consumer use.

- Lithium-ion – Li-ion is replacing many applications that were previously served by lead and nickel-based batteries. Due to safety concerns, Li-ion needs a protection circuit. It is more expensive than most other batteries, but high cycle count and low maintenance reduce the cost per cycle over many other chemistries.

Table 1 compares the characteristics of the four commonly used rechargeable battery systems, showing average performance ratings at time of publication. Li-ion is divided into different types, named by their active materials, which are cobalt, manganese, phosphate and titanate. (See BU-205: Types of Lithium-ion.)

Missing from in the list is the popular lithium-ion-polymer that gets its name from the unique separator and electrolyte system. Most are a hybrid version that shares performance with other Li-ion. Also missing is the rechargeable lithium-metal, a battery that, once the safety issues are resolved, has the potential of becoming a battery choice with extraordinarily high specific energy and good specific power. The table only addresses portable batteries and excludes large systems that resemble a refinery.

Specifications	Lead Acid	NiCd	NiMH	Li-ion[1] Cobalt	Li-ion[1] Manganese	Li-ion[1] Phosphate
Specific energy (Wh/kg)	30–50	45–80	60–120	150–250	100–150	90–120
Internal resistance	Very Low	Very low	Low	Moderate	Low	Very low
Cycle life[2] (80% DoD)	200–300	1,000[3]	300–500[3]	500–1,000	500–1,000	1,000–2,000
Charge time[4]	8–16h	1–2h	2–4h	2–4h	1–2h	1–2h
Overcharge tolerance	High	Moderate	Low	Low. No trickle charge		
Self-discharge/ month (room temp)	5%	20%[5]	30%[5]	<5% Protection circuit consumes 3%/month		
Cell voltage (nominal)	2V	1.2V[6]	1.2V[6]	3.6V[7]	3.7V[7]	3.2–3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20 typical Some go to higher V		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75V	1.00V		2.50–3.00V		2.50V
Peak load current Best result	5C[8] 0.2C	20C 1C	5C 0.5C	2C <1C	>30C <10C	>30C <10C
Charge temperature	–20 to 50°C (–4 to 122°F)	0 to 45°C (32 to 113°F)		0 to 45°C[9] (32 to 113°F)		
Discharge temperature	–20 to 50°C (–4 to 122°F)	–20 to 65°C (–4 to 149°F)		–20 to 60°C (–4 to 140°F)		
Maintenance requirement	3–6 months[10] (toping chg.)	Full discharge every 90 days when in full use		Maintenance-free		
Safety requirements	Thermally stable	Thermally stable, fuse protection		Protection circuit mandatory[11]		
In use since	Late 1800s	1950	1990	1991	1996	1999
Toxicity	Very high	Very high	Low	Low		
Coulombic efficiency[12]	~90%	~70% slow charge ~90% fast charge		99%		
Cost	Low	Moderate		High[13]		

Table 1: Characteristics of commonly used rechargeable batteries. The figures are based on average ratings of commercial batteries at time of publication. Specialty batteries with above-average ratings are excluded.

1. Combining cobalt, nickel, manganese and aluminum raises energy density up to 250Wh/kg.
2. Cycle life is based on the depth of discharge (DoD). Shallow DoD prolongs cycle life.
3. Cycle life is based on battery receiving regular maintenance to prevent memory.
4. Ultra-fast charge batteries are made for a special pupose. (See BU-401a: Fast and Ultra-fast Chargers)
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 and age increase self-discharge.
6. 1.25V is traditional; 1.20V is more common. (See BU-303: Confusion with Voltages).
7. Manufacturers may rate voltage higher because of low internal resistance (marketing).
8. Capable of high current pulses; needs time to recuperate.
9. Do not charge Li-ion below freezing. (See BU-410: Charging at High and Low Temperatures.)
10. Maintenance may be in the form of equalizing or topping charge* to prevent sulfation.
11. Protection circuit cuts off below about 2.20V and above 4.30V on most Li-ion; different voltage settings apply for lithium-iron-phosphate.
12. Coulombic efficiency is higher with quicker charge (in part due to self-discharge error).
13. Li-ion may have lower cost-per-cycle than lead acid.

* Topping charge is applied on a battery that is in service or storage to maintain full charge and to prevent sulfation on lead acid batteries.

Last updated 2019-08-06

*** 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 suggestion or would like to report an error, please use the "contact us" form or email us at: BatteryU@cadex.com. We like to hear from you but we cannot answer all inquiries. We recommend posting your question in the comment sections for the Battery University Group (BUG) to share.

Or Jump To A Different Article

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Comments (37)

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 ir 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 a 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 a 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 respectivally 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 dont discharge by itself when left unused for months? It should be compact and able to supply atleast 5V of energy.

On November 14, 2013 at 3:14am

Dave wrote:

What about Nickle Iron batteries (Knife Cells) ??

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

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 bimedical equipment use and communication equipment use,please advize by email your recomended 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 advize us on the machinery and equipment required.

On April 24, 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 aktive before going from pulse to continukus?

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 Phoshpate) from 80% discharge to 90% charge from a 100 kW generator?

On May 20, 2015 at 10:21pm

Shivam Lal wrote:

Question: Why do Li ion batteries cost so much more than other secondary (rechargable) batteries?

On April 11, 2016 at 11:15am

Anne wrote:

This didn’t help. I asked for properties of primary cell.

On June 22, 2016 at 3:30am

Rahul wrote:

i am looking for the Percentage of Nickel Hydroxide used in Rechargeable batteries and the amount of Nickel Hydroxide required by the Rechargeable batteries Industry globally.

On June 24, 2016 at 7:08am

Paul wrote:

Hi,

one point i am struggling with, is the relationship between the peukert effect and coulombic efficiency… mostly in Lead-Acid technology.

I basically wonder whether Coulombic Efficiency is “included” by the Peukert Effect or if they must be added up.

An example:
- If I am discharging an automoive with a current C/5 for x hours, and need to restore the same amount of charge.
  - I can use the Peukert Effect calculation to estimate the loss in terms of SoC @ C/5 (compared to the 20h rated C given by the specs).
- But then do I also need to factor the ~90% coloumbic efficiency ratio to restore an equivalent amount of charge ?

Thanks for your help,
Paul

On September 21, 2016 at 7:55am

Anouar wrote:

Hi
schematic current charge of battery li-ion 3.7v télephone mobile of Ltspice,
thank you

On October 5, 2016 at 5:04pm

Faith wrote:

I need to know why is lead important to Secondary cells?

On November 22, 2016 at 4:22pm

Ernst wrote:

Thank you for all the information on these pages.
They help me in a great way!
For myself as to inform others!

On August 13, 2017 at 11:24am

John Paterson Jr wrote:

Any information on the Lithium Iron Phosphate (LiFeSO4) rechargeable battery?

On August 13, 2017 at 11:32am

John Paterson Jr wrote:

I meant Lithium Iron Phosphate (LiFePO4).

On February 8, 2018 at 10:12pm

David Buchan-Terrell wrote:

Two questions: !:I have tried to charge Li-ion cells in series. Only one charges. @What is the Boost for over discharged Li-ion.

On February 13, 2018 at 2:04pm

David Buchan-Terrell wrote:

What is the ‘Booster’ voltage for a 3.75 volt lithium cell. It is the oversized AAA type.

On August 9, 2018 at 2:26am

Niraj wrote:

I want to know that why secondary batteries are not used in transistors

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On June 14, 2019 at 4:29am

Mark Troll wrote:

What is the energy efficiency (energy out/ energy in) for each type of battery?

On February 24, 2020 at 7:49pm

David J. Kavanaugh wrote:

In my previous comment, I mentioned my sister's neighbor's 'Scooter' catching fire after being left on the charger too long. Scooters, as I recall, have lead acid batteries. Your guess is as good as mine (probably better) as to why this unit caught fire. Either way, it's probably, still a good idea to keep track of one's charging, I suppose. What can I say?