

Batteries and Energy Storage.

Dr Owen Williams – University of Wales TSD:

You will all be familiar with a range of standard batteries that you use on a daily basis, but it is interesting to look into the actual specifications in more detail to better understand the electrical characteristics of the battery, chemistry, type, charge capacity, current capability etc.

Let's start with the most commonly used battery around the place today.



Generally, these are the batteries you will find in most supermarkets, and are some of the most popular for most general applications.

There are a huge range of AA batteries on the market, from the expensive type like the Duracell, to the cheaper type what you can buy in a £1 store for a pack of 50!

Needless to say, I cannot find the specification and product sheets for these cheap batteries, but feel the weight of the things!

I always buy these batteries for anything important!

All of my devices, or the important kids' toys use these Duracell ProCell (formally Duracell Industrial).

I have always believed them to be a better class of battery than the versions you can buy off the shelf in Tesco.



But then I found these!!

“ **Energizer® Ultimate Lithium™** batteries are THE best batteries you can buy when compared against other **AA** disposables. “

But are they really any better?



DURACELL®



PLUS POWER

MN1500

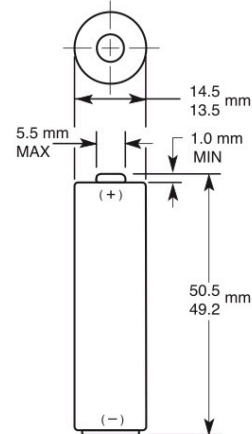
Size: AA (LR6)

Alkaline-Manganese Dioxide Battery

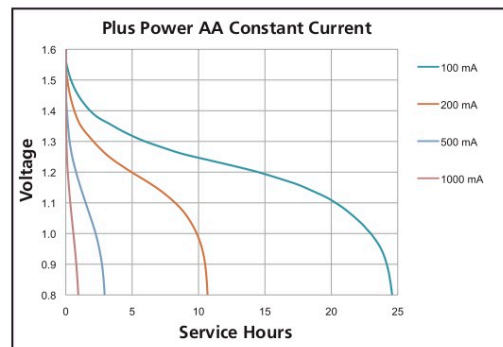
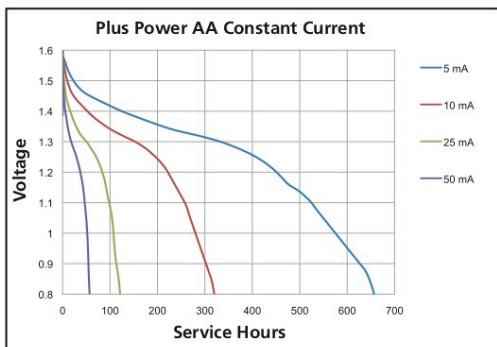
Zn/MnO₂



Nominal voltage	1.5 V
Impedance	120 m-ohm @ 1 kHz
Typical weight	24 g (0.8 oz)
Typical volume	8.4 cm ³ (0.5 in ³)
Terminals	Flat
Storage temperature range	5°C to 30°C (41°F to 86°F)
Operating temperature range	-20°C to 54°C (-4°F to 130°F)
Designation	IEC: LR6



Dimensions shown are IEC standards



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BATTERIES

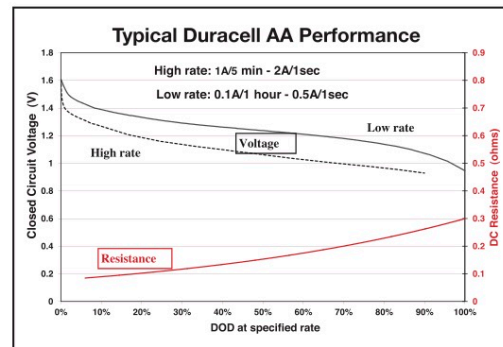
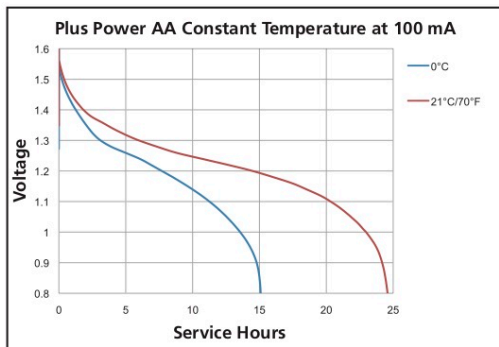
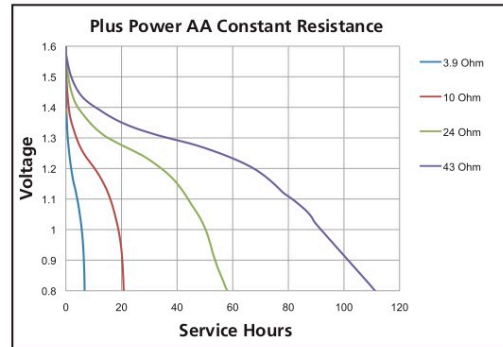
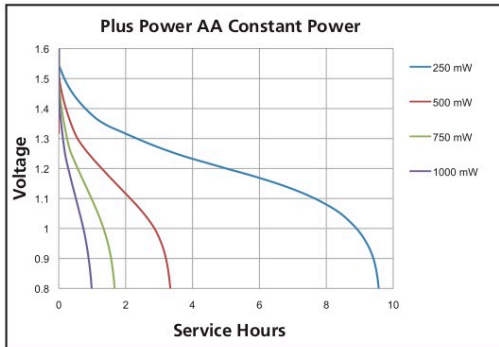
Berkshire Corporate Park
Bethel, CT. 06801 U.S.A.
Telephone: Toll-free 1-800-544-5454
www.duracell.com

Delivered capacity is dependent on the applied load, operating temperature and cut-off voltage. Please refer to the charts and discharge data shown for examples of the energy/service life that the battery will provide for various load conditions.

This data is subject to change. Performance information is typical. Contact Duracell for the latest information.

MN15PPWE0613

Page 1 of 2



PC1500

Size: AA (LR6)

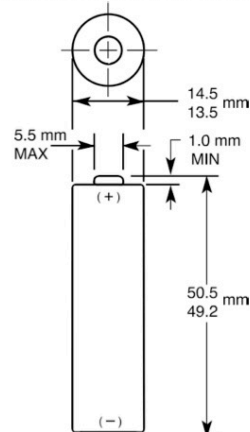
Alkaline-Manganese Dioxide Battery

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Procell AA Constant Current



Procell AA Constant Current



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PC15US1214

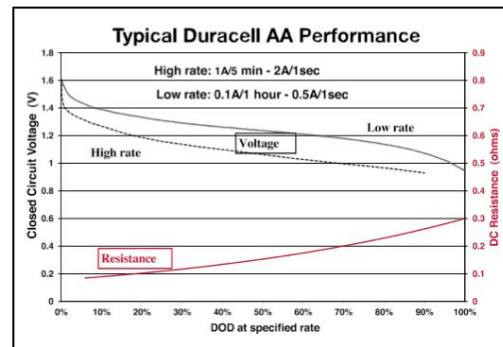
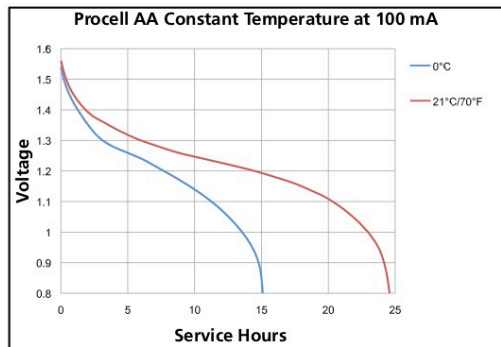
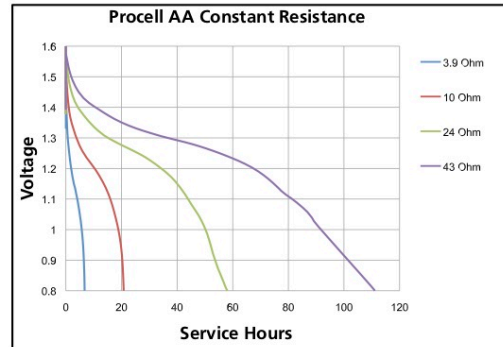
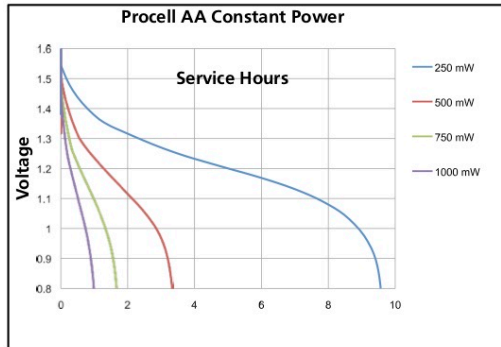


PC1500

Size: AA (LR6)

Alkaline-Manganese Dioxide Battery

Zn/MnO₂



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PC15US1214

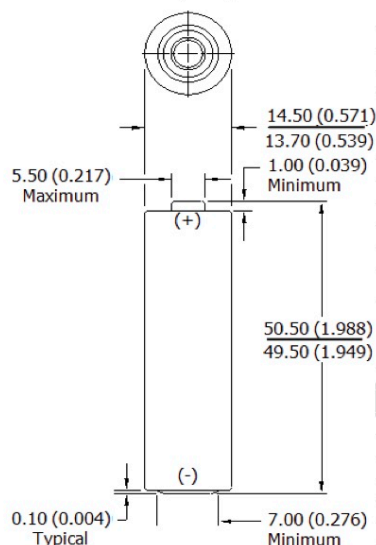
ENERGIZER L91

Ultimate Lithium



Industry Standard Dimensions

mm (inches)



Specifications

AA

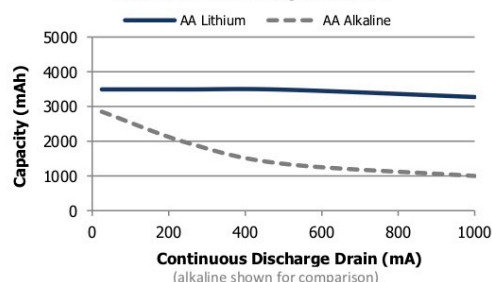
Classification:	"Cylindrical Primary Lithium"
Chemical System:	Lithium/Iron Disulfide (Li/FeS ₂)
Designation:	ANSI 15-LF, IEC-FR14505 (FR6)
Nominal Voltage:	1.5 Volts
Sizing Compatibility:	E91 NH15 1215
Storage Temp:	-40°C to 60°C (-40°F to 140°F)
Operating Temp:	-40°C to 60°C (-40°F to 140°F)*
Typical Weight:	15 grams (0.5 oz.)
Typical Volume:	8.0 cubic centimeters (0.49 cubic inch)
Max Discharge:	2.5 amps continuous
(single battery only)	4.0 amps pulse (2 sec on / 8 sec off)
Lithium Content:	Less than 1 gram
Typical IR:	120 to 240 milliohms (depending on method)
Shelf Life:	20 years at 21°C
More Details:	On-Line Catalog-Application Manual (Li/FeS ₂)
Shipping:	Please refer to PSDS Document
Certifications:	



*All data shown tested at 21°C unless otherwise stated.

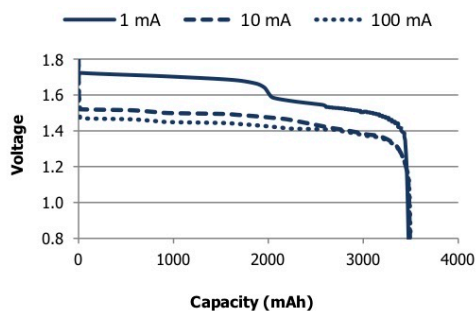
Milliamp-Hours Capacity

Constant Current Discharge to 0.8 Volts



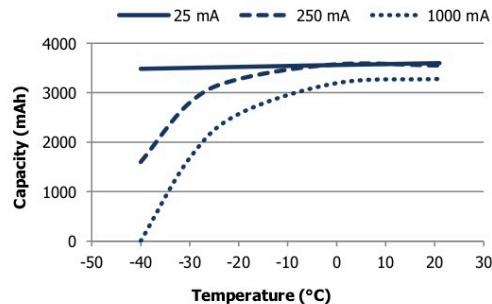
Discharge Profile

Constant Current Discharge



Temperature Effects on Capacity

Constant Current Discharge



Important Notice

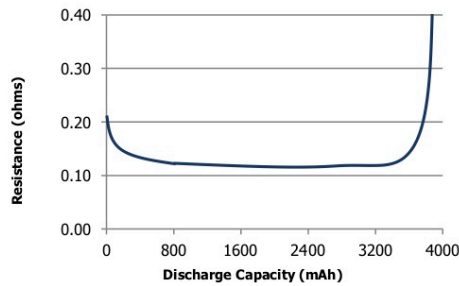
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ENERGIZER L91

AA

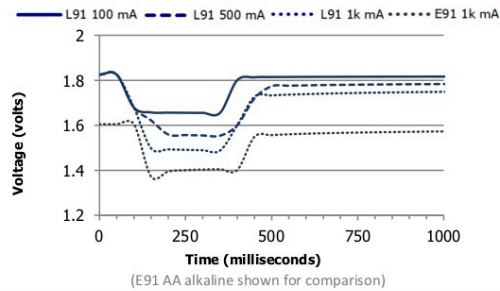
Internal Resistance Profile

Cell Ohmic Resistance - Dual Pulse Method



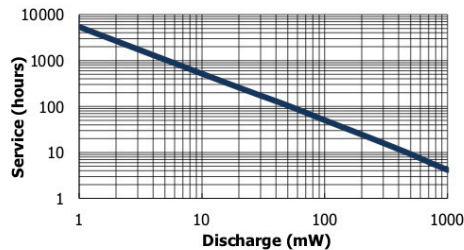
Pulse Response

Open Circuit Voltage - 100/500/1k mA Pulse



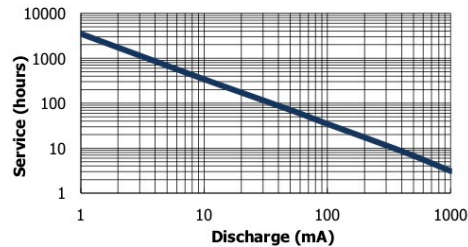
Constant Power Performance

Typical Characteristics to 0.8 Volts



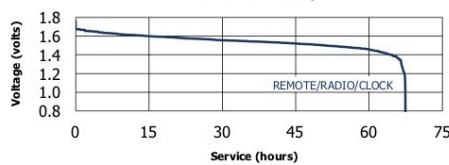
Constant Current Performance

Typical Characteristics to 0.8 Volts



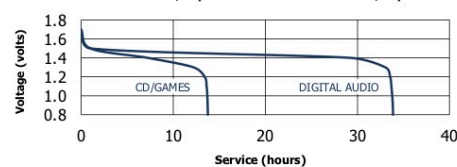
Application Tests

REMOTE/RADIO/CLOCK
50 mA 1 hr/8 hrs day



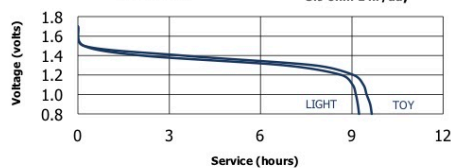
Application Tests

CD/GAMES 250 mA 1 hr/day
DIGITAL AUDIO 100 mA 1 hr/day



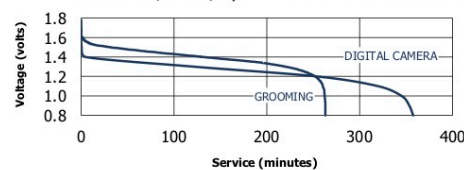
Application Tests

PORTABLE LIGHTING 3.3 ohm LIF
TOY 3.9 ohm 1 hr/day



Industry Standard Tests

PERSONAL GROOMING 750 mA 2 min/hr 8 hrs/day
DIGITAL CAMERA 1.5/.65K mW 2/.1/27.9s 10X



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Moral of the Story.... READ THE SPEC SHEETS!!

(ProCell are actually cheaper, so I'm not a total idiot! ☺)

Automotive Batteries and Energy Storage.

Dr Owen Williams – University of Wales TSD:



Manufacturer's Part Number S5A08
Length – 278 mm
Width – 175 mm
Height Inc Terminals – 190 mm
Weight - 20.4 kg
Voltage - 12V
Ah - 70
Cold Cranking - 760
Hold Down - B13
Layout - RH+
Terminal – A

So what do all these things mean, and what parameters are important to us?

Electrically, we have the obvious 'Voltage', but what about 'Ah' and 'Cold Cranking'?

Looking back a page or two to the Energizer Lithium, we can see a graph for 'Discharge Profile' which shows how the voltage drops as the battery is discharged.

The 'capacity' of this little AA battery can be seen to be 3500 mAh (milli-Amp-Hours) Or alternatively, 3.5Ah.

The Bosch S5A08 above has a capacity of 70Ah... 20 times as much! ... Seems reasonable..?

This Ah or mAh, is a measure of how much 'charge' (coulombs) the battery holds. But this is not the complete picture. The voltages are different. Let's get things back into Joules!

The amount of Energy stored in a battery is measured in many ways, but let's stick to Joules for now, since we all know about that!

An 'Amp Hour' has the units

$$Ah = \frac{C}{s} \cdot 3600 = 3600C$$

So, and Amp Hour is a measure of Coulombs (Charge)...

From our earlier equation, we can see that:

$$Volts = \frac{Joules}{Coulomb} = \frac{Watts}{Amp}$$

If we want Joules, we need *Coulombs x Volts*

$$Joules = Coulombs \cdot Volts = \frac{Watts \cdot Coulomb}{Amp}$$

So, for our little AA Energizer Lithium:

$$Energizer\ AA = 3.5Ah \cdot 1.5V \cdot 3600 = 18,900\ Joules$$

And our Bosch S5A08

$$Bosch\ S5A08 = 70Ah \cdot 12V \cdot 3600 = 3,024,000\ Joules$$

Now the Bosch has 160 times as much capacity as the Energiser AA

Seems better!

What about the batteries in the class?

Conversions from mAh to Joules (Recap)

Dr Owen Williams – University of Wales TSD:

How to convert mAh to Joules

Since an Amp Hour (Ah) is a measure of **charge** (measured in "Coulombs") whereas a Joule is a measure of **energy**, you can't convert mAh to Joules without first knowing the voltage with which the charge was transferred.

Given that voltage the conversion is just:

$$\text{Charge (C)} \times \text{Voltage (V)} = \text{Energy (J)}$$

and,

$$\text{Current (A)} \times \text{time (seconds)} = \text{Charge (C)}$$

To find the mAh to Joule conversion we first find the charge in a mAh.

mA means 1/1000 of an Amp for an hour and there are $60 \times 60 = 3600$ seconds per hour.

So,

$$1\text{mAh} = 0.001 \text{ Amps} \times 3600 \text{ seconds} = 3.6 \text{ Coulombs of charge.}$$

Choosing 1 Volts for the voltage, we can now convert mAh to Joules.

$$3.6 \text{ (C)} \times 1 \text{ (V)} = 3.6 \text{ (J)}$$

We say at 1 Volts, 1mAh of charge equals 3.6 Joules of energy.

This is a handy value for mAh to Joule conversions.

For any voltage, mAh X voltage x 3.6 = Joules of energy.

For any voltage, Ah X voltage x 3600 = Joules of energy.

For example. A 7.2 Volt battery that delivers 100 mAh of charge has delivered,
 $100 \times 7.2 \times 3.6 = 2592$ Joules of energy.



As we saw above, since a mAh is 1/1000 of an Ah, **to convert Ah (amp hours) to Joules** just use $1000 \times 3.6 = 3600$ as the conversion factor instead of 3.6.

What's the difference between an Ah and a Wh?

An Amp Hour (Ah) is a measure of **charge** (measured in "Coulombs") whereas a Watt Hour (Wh) is a measure of **energy**. The two are related by **voltage**.

So a 36 V battery stores twice the energy (Wh) of an 18 V battery.

When only an Ah specification is given it is understood that the voltage that determines the energy this represents is that of the battery (storage device).



In summary, the energy (measured in "Joules") stored in a

36 V, 15 Ah (15,000 mAh) battery is $36 \times 15 = 540$ "Volt-Amp-hours" or Watt - hours.

Where a Volt-Amp-hour (Wh) is 3600 Joules (J).

So, **our OSET battery has stored 1,944,000 Joules** of energy!

That's **pretty close to** the 2,110,000 Joules in **a stick of dynamite**? A good reason to respect storage in batteries!

$$Ah \cdot V = Wh$$

$$Wh = \frac{J}{s} \cdot h = \frac{J}{s} \cdot 3600s = \text{Joules}$$

$$Ah \cdot V \cdot 3600 = \text{Joules}$$

Battery Chemistry and Performance

Dr Owen Williams – University of Wales TSD:

Very generically, we call batteries 'primary' and 'secondary'.

The ones you use in clocks, torches etc are primary, while those in cars, camera and mobile phones are secondary.

Difference lies in their chemistry. Primary battery reactions are one way, and chemicals cannot be recovered.

Secondary batteries have chemicals which react with each other in reversible manner. While using, reactions change the nature of chemicals, and the original chemicals are restored when a current is passed in reverse direction.

Primary batteries are use and throw varieties. They can be used only once and cannot be recharged. Batteries used in hearing aids (zinc air type) are primary. Nearly all AAA, AA, and A types in torches, remote etc are also primary batteries.

Rechargeable batteries you find in use everywhere. Your laptop, mobile phone, cars and bikes etc etc. They can be recharged hundreds of times, and the number of times they can thus be reused by discharging to their minimum limits is called cycle life. For instance, lead acid batteries have life of 300-700 cycles.

TYPES OF RECHARGABLE BATTERY CHEMISTRY

Nickel Cadmium (NiCad) Batteries



Nicads have been around for a very long time and were the only option for many RC applications for decades. These days however, they have largely been replaced by more advanced technologies. However, there are still places where nicad batteries can hold their own.

Nicad Pro's:

- low internal resistance (high-currents)
- low self-discharge
- less affected by low temperatures than some

Nicad Con's:

- heavier/bulkier than other battery technologies
- suffer from memory/voltage-depression
- environmentally unfriendly

A word about memory....

One of the biggest problems that affects nicad batteries is something often referred to as "memory".

This is more accurately referred to as voltage-depression and occurs when a battery is repeatedly charged but only partially discharged.

Over time, the battery appears to lose capacity to the point that only a small percentage of its rated energy storage is still useable.

The only way to recover the lost storage is by cycling the battery through a series of deeper discharge and recharge operations until its capacity is restored.

If you don't have a charger that will allow you to perform these capacity restoring charge/discharge cycles then avoid recharging your nicads when they're only partially discharged, or allow your batteries to discharge until they're nearly flat at least once every dozen charges.

When to use

Nicads continue to be used for a number of 'lower tech' applications, although with the advances in other battery technologies and growing environmental concerns, most manufacturers are now providing more modern options.

Despite the development of hi-capacity and hi-current lithium polymer (LiPo) batteries, some users still prefer to use Nicads as a power source on extremely demanding applications where weight is less of an issue than the ability to safely deliver extremely high currents. However, it is pretty hard to recommend Nicad batteries for general use these days. As you'll find out as you read on, new technologies have largely left Nicads in the dust.

Nickel Metal Hydride (NiMH) batteries
CHEAP, RELIABLE AND EFFECTIVE



Nickel Metal Hydride (NiMH) batteries have largely taken over from nicads in the area of transmitter and receiver packs for Radio Controlled applications.

Although early NiMH cells were sometimes problematic and not well suited to applications such as RC systems, today's versions are far advanced and represent the most practical solution for many applications.

Just about the only problem with NiMH batteries is that many of those available cheaply simply don't have the claimed capacity and can therefore leave users wondering why they're not holding a proper charge.

NiMH Pro's:

- high capacities possible (AA cells of up to 2700mAh)
- no memory/voltage-depression effects
- less of an environmental problem than nicads

NiMH Con's:

- can self-discharge more rapidly than other technologies
- hi-capacity batteries can be delicate and unsuited to receiver packs
- not always the advertised capacity

The essential 'forming charge'.

Whereas nicad cells can be used straight out of the box, NiMH packs require a "forming charge" if you're ever going to see their maximum capacity realized.

This forming charge must be done at no more than the 10-hour charge rate (1/10C) and ensures that the plates inside the cells are properly conditioned for use.

You should not use a peak-detecting "smart" charger for this forming charge as it will almost certainly either false-peak or fail to detect when the battery is fully charged. It's best to just use the standard charger and calculate how many hours will be required to pump 120% of the cell's rated capacity into the battery.

For example, if your wall charger, charges at 50mA and you're trying to form-charge a 1500mAH battery then you need to leave it on for $(1500/50) \times 1.2$ which is 36 hours.

Always keep an eye on a new battery that's being form-charged to make sure it doesn't get warm. If it does, then it's taken a full charge (it was probably half-charged to start with).

When to use

Right now, NiMH batteries are about the best choice for transmitter packs and receiver packs in many models.

Caution must be observed when using hi-capacity NiMH cells (over 1650mAH in AA size) because these are more easily damaged by over-charging or charging at too high a current.

While the higher capacity NiMH cells (up to 2700mAH in AA size) might seem to be better, they will self-discharge more quickly when the application is turned off and can only be charged at currents of about 250mAH making fast charging impossible.

Lithium Polymer (LiPo) batteries

MAKING ELECTRIC FLIGHT REALLY PRACTICAL



Before the LiPo came along, most batteries tended to be heavy and offered only limited performance and endurance. Heavy nicads or NiMH batteries represented a lot of weight and that really limited the possibility of very light weight applications.

However, the LiPo has changed all that and now has become the mainstay power source for a number of airborne applications where weight is a real handicap. This has hugely influenced the 'drone' industry.

LiPo Pro's:

- highest power/weight ratio
- very low self-discharge
- less affected by low temperatures than some

LiPo Con's:

- intolerant of over-charging
- intolerant of over-discharging
- significant fire risk

LiPo precautions:

Whenever a lot of energy is stored in a small space there are dangers. Just as dynamite, TNT and nitro-glycerine represent a huge danger if abused or mis-used, so it is with LiPo batteries.

There have been many well documented instances of LiPo batteries becoming powerful incendiary devices when over-charged or physically damaged, so you need to be very careful when using these batteries.

Always charge them in a safe environment -- preferably placing them inside a fireproof box or bag "just in case".

Always use a suitable charger and charge-rate, don't ever be tempted to try and charge too fast or too long. The results could be very nasty.

And never over-discharge a LiPo. Unlike most other battery types, running a LiPo too flat will permanently damage it. Subsequent attempts to recharge an over-discharged LiPo can result in a loss of capacity (at best) and a nasty fireball (at worst).

When to use

If you want to obtain maximum performance from an electric-powered application, then nothing really compares to LiPo batteries.



LiPo packs come in very specific voltages. A LiPo cell has a nominal voltage of 3.7V. For the 7.4V battery above, that means that there are two cells in series (which means the voltage gets added together).

Since a two-cell LiPo produces 7.2 volts, a regulator may be essential for many applications or it's very likely the equipment will be damaged through overheating.

Lithium Iron Phosphate (LiFePO₄) and A123 batteries
PERHAPS THE BEST BATTERY TECHNOLOGY AVAILABLE



Imagine if we could combine the safety and durability of nicads with the capacity and light-weight of LiPos. Wouldn't that be the best of all worlds?

Well that's pretty much what you get with the latest battery technology known as Lithium Iron Phosphate (LiFePO₄).

Batteries based on this technology have almost the same power to weight ratio as LiPos but are far more tolerant of over and under-charging.

In a situation where a LiPo might explode into flames, the LiFePO₄ cell will probably just vent some harmless gas.

LiFePO₄ Pro's:

- very high power/weight ratio
- very low self-discharge
- more tolerant of over/under-charge/discharge
- can be used for RC gear without needing regulators

LiFePO₄ Con's:

- Only a limited range of battery capacities currently available
- Odd-sizes for most cells (not AA, C, D, etc)
- LiFePO₄-capable charger needed

LiFePO₄ and A123, what's the difference?

Some people tend to use the terms LiFePO₄ and A123 interchangeably -- but there is a significant difference between the two.

The fact is that A123 is a brand name for a specific type of LiFePO4 battery that incorporates nano-technology to significantly increase the current-handling capabilities.

The capabilities of an A123 battery are truly impressive -- with a 2300mAH pack being able to deliver currents of up to 100A for 10 seconds or more without damage. That's a 40C (we'll come back to that!) rating.

A standard LiFePO4 battery by comparison, may have only a 3-5C rating which is perfectly adequate for most applications but nowhere near as suited to hi-current applications (such as electric power) as a true A123.

When to use

Well the answer to this is simple -- use LiFePO4/A123 batteries whenever it's possible.

Given that LiFePO4 batteries are cheaper, smaller, lighter and better in just about every way than any of the other technologies there's little reason not to use them.

High-current LiFePO4 batteries are now becoming available to replace LiPos for electric power. They're a little bigger and heavier than the equivalent LiPo but for many folks, this will be a small price to pay for the dramatically increased safety and robustness they offer.



Understanding Battery Specifications

Dr Owen Williams – University of Wales TSD:



This summary provides an introduction to the terminology used to describe, classify, and compare batteries for hybrid, plug-in hybrid, and electric vehicles. It provides a basic background, defines the variables used to characterize battery operating conditions, and describes the manufacturer specifications used to characterize battery nominal and maximum characteristics.

Battery Basics

- **Cell, modules, and packs** – Hybrid and electric vehicles have a high voltage battery pack that consists of individual modules and cells organized in series and parallel. A cell is the smallest, packaged form a battery can take and is generally on the order of one to six volts. A module consists of several cells generally connected in either series or parallel. A battery pack is then assembled by connecting modules together, again either in series or parallel.
- **Battery Classifications** – Not all batteries are created equal, even batteries of the same chemistry. The main trade-off in battery development is between power and energy: batteries can be either high-power or high-energy, but not both. Often manufacturers will classify batteries using these categories. Other common classifications are High Durability, meaning that the chemistry has been modified to provide higher battery life at the expense of power and energy.
- **C- and E- rates** – In describing batteries, discharge current is often expressed as a C-rate in order to normalize against battery capacity, which is often very different between batteries. A C-rate is a measure of the rate at which a battery is discharged relative to its maximum capacity. A 1C rate means that the discharge current will discharge the entire battery in 1 hour. For a battery with a capacity of 100 Amp-hrs, this equates to a discharge current of 100 Amps. A 5C rate for this battery would be 500 Amps, and a C/2 rate would be 50 Amps. Similarly, an E-rate describes the discharge power. A 1E rate is the discharge power to discharge the entire battery in 1 hour.
- **Secondary and Primary Cells** – Although it may not sound like it, batteries for hybrid, plug-in, and electric vehicles are all secondary batteries. A primary battery is one that can not be recharged. A secondary battery is one that is rechargeable.

Battery Condition

This section describes some of the variables used to describe the present condition of a battery.

State of Charge (SOC)(%) – An expression of the present battery capacity as a percentage of maximum capacity. SOC is generally calculated using current integration to determine the change in battery capacity over time.

- **Depth of Discharge (DOD) (%)** – The percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity. A discharge to at least 80 % DOD is referred to as a deep discharge.
- **Terminal Voltage (V)** – The voltage between the battery terminals with load applied. Terminal voltage varies with SOC and discharge/charge current.
- **Open-circuit voltage (V)** – The voltage between the battery terminals with no load applied. The open-circuit voltage depends on the battery state of charge, increasing with state of charge.
- **Internal Resistance** – The resistance within the battery, generally different for charging and discharging, also dependent on the battery state of charge. As internal resistance increases, the battery efficiency decreases and thermal stability is reduced as more of the charging energy is converted into heat.

Battery Technical Specifications

This section explains the specifications you may see on battery technical specification sheets used to describe battery cells, modules, and packs.

- **Nominal Voltage (V)** – The reported or reference voltage of the battery, also sometimes thought of as the “normal” voltage of the battery.
- **Cut-off Voltage** – The minimum allowable voltage. It is this voltage that generally defines the “empty” state of the battery.
- **Capacity or Nominal Capacity (Ah for a specific C-rate)** – The coulometric capacity, the total Amp-hours available when the battery is discharged at a certain discharge current (specified as a C-rate) from 100 percent state-of-charge to the cut-off voltage. Capacity is calculated by multiplying the discharge current (in Amps) by the discharge time (in hours) and decreases with increasing C-rate.
- **Energy or Nominal Energy (Wh (for a specific C-rate))** – The “energy capacity” of the battery, the total Watt-hours available when the battery is discharged at a certain discharge current (specified as a C-rate) from 100 percent state-of-charge to the cut-off voltage. Energy is calculated by multiplying the discharge power (in Watts) by the discharge time (in hours). Like capacity, energy decreases with increasing C-rate.

- **Cycle Life (number for a specific DOD)** – The number of discharge-charge cycles the battery can experience before it fails to meet specific performance criteria. Cycle life is estimated for specific charge and discharge conditions. The actual operating life of the battery is affected by the rate and depth of cycles and by other conditions such as temperature and humidity. The higher the DOD, the lower the cycle life.
- **Specific Energy (Wh/kg)** – The nominal battery energy per unit mass, sometimes referred to as the gravimetric energy density. Specific energy is a characteristic of the battery chemistry and packaging. Along with the energy consumption of the vehicle, it determines the battery weight required to achieve a given electric range.
- **Specific Power (W/kg)** – The maximum available power per unit mass. Specific power is a characteristic of the battery chemistry and packaging. It determines the battery weight required to achieve a given performance target.
- **Energy Density (Wh/L)** – The nominal battery energy per unit volume, sometimes referred to as the volumetric energy density. Specific energy is a characteristic of the battery chemistry and packaging. Along with the energy consumption of the vehicle, it determines the battery size required to achieve a given electric range.
- **Power Density (W/L)** – The maximum available power per unit volume. Specific power is a characteristic of the battery chemistry and packaging. It determines the battery size required to achieve a given performance target.
- **Maximum Continuous Discharge Current** – The maximum current at which the battery can be discharged continuously. This limit is usually defined by the battery manufacturer in order to prevent excessive discharge rates that would damage the battery or reduce its capacity. Along with the maximum continuous power of the motor, this defines the top sustainable speed and acceleration of the vehicle.
- **Maximum 30-sec Discharge Pulse Current** – The maximum current at which the battery can be discharged for pulses of up to 30 seconds. This limit is usually defined by the battery manufacturer in order to prevent excessive discharge rates that would damage the battery or reduce its capacity. Along with the peak power of the electric motor, this defines the acceleration performance (0-60 mph time) of the vehicle.
- **Charge Voltage** – The voltage that the battery is charged to when charged to full capacity. Charging schemes generally consist of a constant current charging until the battery voltage reaching the charge voltage, then constant voltage charging, allowing the charge current to taper until it is very small.
- **Float Voltage** – The voltage at which the battery is maintained after being charge to 100 percent SOC to maintain that capacity by compensating for self-discharge of the battery.

- **(Recommended) Charge Current** – The ideal current at which the battery is initially charged (to roughly 70 percent SOC) under constant charging scheme before transitioning into constant voltage charging.
- **(Maximum) Internal Resistance** – The resistance within the battery, generally different for charging and discharging.



The battery pack of the second-generation Toyota Prius consists of 28 Panasonic prismatic nickel metal hydride modules, each containing six 1.2 volt cells connected in series to produce a nominal voltage of 201.6 volts.

The total number of cells is 168, compared with 228 cells packaged in 38 modules in the first-generation Prius. The pack is positioned behind the back seat.

The weight of the complete battery pack is 53.3 kg and it has a capacity of 6.5Ah.

The discharge power capability of the Prius pack is about 20 kW at 50 percent state-of-charge. The power capability increases with higher temperatures and decreases at lower temperatures. The Prius has a computer that's solely dedicated to keeping the Prius battery at the optimum temperature and optimum charge level. The Prius supplies conditioned air from the cabin as thermal management for cooling the batteries. The air is drawn by a 12-volt blower installed above the driver's side rear tire well.

$$201.6 \times 6.5 \times 3600 = 4.717 \text{ MJ}$$

$$20\text{kW} = 4,171,440 \text{ J} / \text{s}$$

$$S = 4,171,440 / 20,000$$

$$S = 208.57 \text{ seconds}$$