CHOOSING A RECHARGEABLE BATTERY

Advances in battery technology have now resulted in quite a range of different rechargeable (secondary) batteries from which to choose. This can make it hard to decide which type is the best choice for some applications. The aim of this data sheet is to give you a basic idea of the types that are available, how they work, and the things to consider when you're trying to decide which one is most suitable for a given job.

By the way we're going to limit our discussion mainly to the types of battery used for powering domestic and light industrial electronic/electrical equipment. We won't be considering heavy-duty automotive or traction batteries, or those used for very large uninterruptible power supplies, or those designed for specialised applications such as solar power supplies.

To begin, there are five main types of rechargeable battery now in common use for powering electronic and electrical equipment: the **sealed lead-acid** or 'SLA' battery (sometimes called the 'gel cell'), the **rechargeable alkaline-manganese** or 'RAM' battery, the **nickel-cadmium** or 'NiCad' battery, the **nickel-metal hydride** or 'NiMH' battery and the **lithium-ion** or 'Li-ion' battery. But before we look at each of these more closely, we need to clarify a few points about secondary batteries in general.

Battery capacity

Like primary batteries, secondary batteries are basically a device which stores electrical energy in chemical form. They differ from one another mainly in terms of the amount of electrical energy they can store and deliver. Broadly speaking the larger the physical size of a battery, the more electrical energy it can store.

The gross electrical storage capacity of a battery is usually specified in **ampere-hours** (Ah), or for small batteries in **milliamp-hours** (mAh). As you can see these units equate directly to the quantity of electrical charge they store: 1Ah is the same as 3600 coulombs of charge, while 1mAh is the same as 3.6 coulombs. (Remember that 1 amp = 1 coulomb per second)

Needless to say this stored charge can be delivered by the battery at various rates during *discharge*, and also replaced at various rates during its *recharging*. This is discussed in more detail shortly.

Energy density

Physical battery size isn't the only factor that determines how much electricity a battery can store. Another important factor is the chemical storage system used in the battery — its *chemistry*, if you like. This factor tends to control a battery's **energy storage density**: how much electrical energy can be stored per kilogram of battery weight. The energy density of batteries is usually specified in **watt-hours per kilogram** (Wh/kg).

The various types of rechargeable battery differ quite significantly in terms of energy density. For example the long established SLA type is lowest, with a figure of about 30Wh/kg, while NiCads offer up to double this figure and the newer NiMH type can provide up to 80Wh/kg. The most expensive Li-ion type offer even higher density, at up to 140Wh/kg or so.

The C rate

As mentioned above, a battery can be both charged and discharged at various rates — i.e., the current level, which in turn determines how long the charging takes and how long the discharging lasts. These rates are usually specified in terms of the 'C Rate', where **C** is the battery's nominal capacity in Ah or mAh.

Not surprisingly a discharge rate of 1C means that the battery is discharged at the same rate as its nominal capacity, so at this rate it takes one hour before being nominally discharged. For example a 1.8Ah battery would be delivering 1.8A at the 1C rate, and should hopefully be able to do this for one hour before being 'exhausted'.

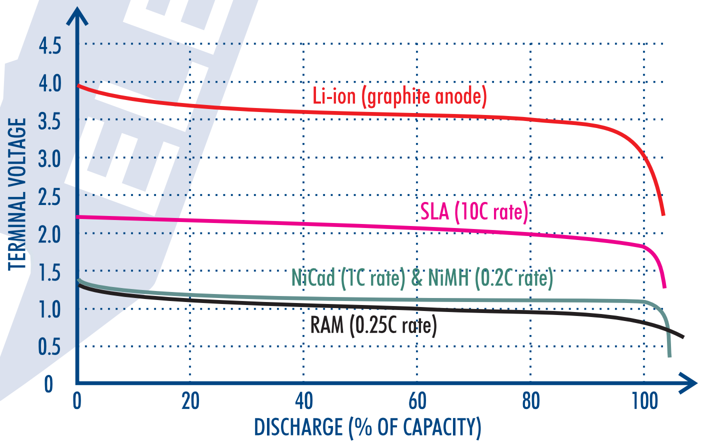
Discharging the battery at a *lower* rate will allow it to do so for a longer time, of course. So at the 0.5C rate the battery's nominal charge should last for two hours, while at the 0.05C rate it should last for 20 hours.

Conversely if the battery is being discharged at a *higher* rate, the discharge time will become less than one hour. So at the 2C rate it would in theory last for 30 minutes, or for only 12 minutes at the 5C rate. Higher rates would give even shorter times...

The C rate is also used to describe charging, as well as discharging. Charging rates of greater than 0.5C are usually described as 'fast' charging, rates between 0.2C and 0.5C as 'normal' charging, rates between 0.05C and 0.2C as 'slow' or 'trickle' charging and lower rates again as 'float' charging.

Although this may sound relatively straightforward, the relationship between discharge/charge rate and battery capacity is actually quite a complex one. Fast charging or discharging can generate heat inside the battery which lowers its chemical efficiency, and hence reduces its effective capacity. On the other hand very slow charging or discharging can also give lower effective capacity due to the fact that all batteries suffer from internal self-discharging effects.

In fact the different types of battery react rather differently at various charging or discharging levels, and this is another factor which needs to be taken into account when selecting the type of battery to be used.



Discharge curves for one cell of each of the five main types of rechargeable battery, compared at typical discharge rates.

RECHARGEABLE BATTERY COMPARISON CHART								
TYPE (CHEMISTRY)	NOMINAL CELL VOLTS	ENERGY DENSITY (Wh/kg)	CYCLE LIFE	CHARGING TIME	MAXIMUM DISCHARGE RATE	COST	PROS & CONS	TYPICAL APPLICATIONS
SLA	2.0	LOW (30)	LONG (Shallow cycles)	8 - 16h	MEDIUM (0.2C)	LOW	Low cost, low self-discharge; happy float charging; but prefer shallow cycling	Emergency lighting, UPS's, solar power systems, wheelchairs etc.
RAM	1.1	HIGH (75 initial)	SHORT TO MEDIUM	2 - 6h (pulsed)	MEDIUM (0.3C)	LOW	Low cost, low self-discharge; prefer shallow cycling; no memory effect but short cycle life	Portable emergency lighting, toys, portable radios, cassette & CD players, test instruments, etc.
NiCad	1.2	MEDIUM (40-60)	LONG (Deep cycles)	14 - 16h (0.1C) OR <2h with care (1C)	HIGH (>2C)	MEDIUM	Prefer deep cycling, good pulse capacity; but have memory effect; fairly high self-discharge rate	Portable tools & appliances, model cars & boats, data loggers, camcorders, portable transceivers & test equipment.
NiMH	1.2	HIGH (60-80)	MEDIUM	2 - 4h	MEDIUM (0.2 - 0.5C)	HIGHER	Very compact energy source; but have some memory effect; high self-discharge rate	Cellphones & cordless phones, compact camcorders, laptop computers, PDAs, personal DVD & CD players.
Li-ion	3.6	VERY HIGH (>100)	LONG	3 - 4h (1C + 0.03C)	MED/HIGH (<1C)	VERY HIGH	Very compact, low maintenance; low self-discharge; but need great care with charging	Compact cellphones & notebook PCs, digital cameras and similar very small portable devices.

By the way you can always work out the *actual* charging or discharging current levels corresponding to a given C rate simply by multiplying it by the battery's nominal capacity. So for a 1.4Ah battery the 0.2C rate would correspond to a current of 280mA (0.2 x 1.4A), while the 0.05C rate would translate to 70mA.

Losses & efficiency

Nothing in the real world is perfect, and secondary batteries are no exception: they're never perfectly efficient. Due to internal resistance and other losses, you always have to put more energy into them during charging than they will ever return to the load during discharging. The usual rule of thumb is that 40% of the charging energy is wasted — so to fully charge a battery from 'flat', you typically have to provide it with 140% of its nominal capacity.

So in practice charging a fully discharged battery at the 0.1C rate will generally take not 10 hours, but about 14 hours.

Cycle depth

In addition to the charging and discharging rate, another factor which can influence both the effective capacity and useful working life of a battery is how it's **cycled**. Here a 'cycle' is a single discharge-and-charge sequence.

An important aspect of these cycles is their *depth* — i.e., what proportion of the battery's nominal total charge capacity is drawn from the battery and replaced again each time. So a 'deep' cycle is one where the battery is being almost completely discharged before being recharged, while a 'shallow' cycle is one where only a small proportion of the battery's capacity is being delivered to the load before it's recharged again. (Like 'heavy exercise' and 'light exercise'...)

Some types of battery perform better (i.e., deliver more of their capacity, or have a longer working life) when they're cycled quite deeply, while others perform better with relatively shallow cycling.

A term you've probably heard used is **memory effect**, particularly with respect to NiCad batteries. This describes the tendency for such batteries to gradually lose their useful capacity when subjected to repeated *shallow* cycling. The active materials on the surface of the battery's electrodes gradually change from a huge number of microscopic crystals into smaller numbers of larger and larger crystals, which reduces the total surface area. This is why NiCads are best used for deep cycling applications, and should *never* be float charged.

So again, the kind of cycling involved in an application is another factor which should be considered in choosing the most suitable type of battery.

Cell voltage

Although it's usual to talk about the nominal cell voltage for each type of battery, you should be aware that the actual cell voltage of most batteries varies quite considerably — during both charging and discharging.

For example during normal or fast charging, the voltage across the cells of an SLA battery might be as high as 2.5V. This might drop to 2.2V per cell when the charging stops and the battery is fully charged. Then as the battery is discharged, the cell voltage may slowly droop to the nominal 2.0V, before dropping more rapidly as the cells approach the fully discharged state. Here the cell voltage might be as low as 1.33V, depending on the manufacturer's definition of 'fully discharged'.

So think of the specified cell voltage — and nominal battery voltage — as only a broad approximation. The actual voltage can be 25% higher during charging, or 33% lower when it's 'flat'.

Of course the actual terminal voltage of a battery depends on the number of cells it contains. For example most SLA batteries sold are of either the three-cell type with a nominal terminal voltage of 6V, or the six-cell type with a nominal voltage of 12V. NiCads on the other hand are sold as single cells with a nominal voltage of 1.2V, six-cell batteries with a nominal voltage of 7.2V, eight-cell batteries with a nominal voltage of 9.6V, and so on.

Now let's look briefly at each of the common types of secondary battery used in portable electronic and electrical equipment.

SLA batteries

Sealed lead-acid batteries are a development of the familiar 'flooded' lead-acid battery used for many years in cars and trucks. This is the oldest type of secondary battery, developed nearly 150 years ago by French physician Gaston Planté. It has a positive electrode of lead oxide, a negative electrode of porous metallic lead and sulphuric acid as the electrolyte.

The SLA form uses a gel-type electrolyte rather than a liquid, and electrodes made from lead alloys designed so that during charging, it normally never reaches the stage where gas is generated. This allows it to be sealed (apart from a safety valve), and hence able to be used in almost any position. Since water is not lost the SLA also requires little maintenance, but on the other hand since it's never fully charged (in the theoretical sense) it tends to have a relatively poor energy density — the lowest for all of the sealed rechargeables. As SLAs are also the cheapest rechargeables, this means that they're best suited for applications where low-cost power storage is the main consideration, and bulk/weight is not a problem.

SLAs have the lowest self-discharge rate of any of the rechargeables (about 5% per month). They do not suffer from the memory effect displayed by NiCads, and perform well with shallow cycling. In fact they tend to prefer it to deep cycling, although they perform quite well with intermittent heavy discharging. They can be 'float' charged for long periods without adverse effect, which makes them well suited for applications where power is only needed for brief periods, emergency situations etc. Examples are UPSs and emergency lighting systems.

RAM batteries

The rechargeable alkaline-manganese battery is a recent development from the alkaline manganese-zinc primary battery, developed by Canadian firm Battery Technologies and available commercially from various manufacturers since 1993. Like the primary battery it uses a manganese dioxide positive electrode and a potassium hydroxide electrolyte, but the negative electrode is a special porous zinc gel designed to absorb hydrogen during the charging process. The separator is also laminated to prevent it being pierced by zinc dendrites.

RAM batteries are lower in cost than NiCads and offer a much lower self-discharge rate than either NiCads or NiMH batteries — only about 10% per year. They are also free from the memory effect, are quite happy with shallow cycling and can be rapidly charged using pulsed techniques.

However RAM batteries tend to have a somewhat shorter cycle life than NiCads, especially when deeply cycled. This makes them mainly suitable for low-cost consumer applications where they are subjected to shallow cycling.

NiCad batteries

The basic nickel-cadmium battery was invented in 1899 by Waldmar Jugner, but the modern sealed type dates from about 1947. It uses nickel hydroxide as the positive electrode and cadmium metal/cadmium hydroxide as the negative electrode, with potassium hydroxide as the electrolyte.

Like SLAs, sealed NiCads can be used in virtually any position. They have a higher energy density than SLAs — up to double — and this combined with their relatively low cost makes them very popular for powering compact portable equipment: cordless power tools, instruments, radio transceivers, model boats and cars, and appliances like torches and vacuum cleaners.

NiCads do suffer from the memory effect however, and are therefore not really suitable for applications that involve shallow cycling or spending most of their time on a float charger. They perform best in situations when they're deeply cycled, and also prefer relatively fast charging (especially pulsed charging).

NiCads also have a somewhat higher self-discharge rate than SLAs: about 10% in the first 24 hours after charging, and then about 10% per month. Self discharging also increases significantly with temperature, roughly doubling for each 10°C rise.

Providing they're carefully treated, though, and used for the jobs they're best suited, NiCads can provide very cost-effective energy storage and the longest working life of any of the rechargeables. That's why they're still by far the most popular, despite the appearance of the newer types.

NiMH batteries

The nickel-metal hydride battery is in many ways a development from the NiCad, although they're also related to the hydrogen-nickel oxide batteries used in communications satellites. They basically evolved from the work done in the 1970s into the storage of hydrogen gas in metallic hydrides, but only became practical about 1990.

Like NiCads, NiMH batteries use a nickel/nickel hydroxide positive electrode and potassium hydroxide as the electrolyte. However instead of a cadmium/cadmium hydroxide negative electrode, the NiMH has an electrode made from a hydrogen-storage alloy such as lanthanium-nickel or zirconium-nickel.

NiMH batteries have up to 30% higher energy density than NiCads, but still display some memory effect. They're not as happy with deep discharge cycles, though, and tend to have a shorter working life than NiCads.

Another characteristic of NiMH batteries is that they dissipate heat during charging, and can only be charged at about half the rate of NiCads. Charging is more complicated, and ideally involves temperature sensing.

The self-discharge rate of NiMH batteries is also about 50% higher than NiCads.

With a significantly higher overall cost than NiCads, the main kinds of application where NiMH batteries are most suitable are those which need a very compact source of power, yet do not involve deep cycling. Typical examples are mobile and cordless phones, portable camcorders and laptop computers.

Li-ion batteries

Lithium-ion rechargeable batteries are a recent development from the lithium primary cell, which was invented by G.N. Lewis in 1912 but not marketed commercially until the early 1970s.

Lithium is the lightest of all metals and has the highest electrochemical potential, which gives it the possibility of an extremely high energy density. However the metal itself is highly reactive, and while this isn't a problem with primary cells it poses an explosion risk with rechargeable batteries. For these to be made safe, lithium-ion technology had to be developed; this uses lithium ions from chemicals such as lithium-cobalt dioxide, instead of the metal itself.

The first practical rechargeable Li-ion rechargeable battery was developed by Sony in the late 1980s and marketed in 1990.

Typical Li-ion batteries have a negative electrode of aluminium, coated with a lithium compound such as lithium-cobalt dioxide, lithium-nickel dioxide or lithium-manganese dioxide. The positive electrode is generally of copper, coated with carbon (generally either graphite or coke), while the electrolyte is a lithium salt such as lithium-phosphorus hexafluoride, dissolved in an organic solvent such as a mixture of ethylene carbonate and dimethyl carbonate.

Li-ion batteries have roughly twice the energy density of NiCads, making them the most compact rechargeable yet in terms of energy storage. Unlike NiCads or NiMH batteries they are not subject to memory effect, and have a relatively low self-discharge rate — about 6% per month, less than half that of NiCads. They are also capable of moderately deep discharging, although not as deep as NiCads as they have a higher internal resistance.

On the other hand Li-ion batteries cannot be charged as rapidly as NiCads, and cannot be trickle or float charged either. They are also significantly more costly than either NiCads or NiMH batteries, making them the most expensive rechargeables of all. Part of the reason for this is that they must be provided with built-in protection against both excessive discharging and overcharging (both of which pose a safety risk). Most Li-ion batteries are therefore supplied in self-contained battery packs, complete with 'smart' protective circuitry.

The main applications for Li-ion batteries are therefore where as much energy as possible needs to be stored in the smallest possible space, and with as little weight as possible — and the added cost and 'housekeeping' are of secondary importance. Typical applications are in laptop computers, PDAs, camcorders and cellphones.

Making a choice

Hopefully the foregoing will have given you at least a general idea of the different kinds of rechargeable battery currently available, and their main pros and cons.

It shouldn't be too difficult choosing the most suitable battery for a given application, once you take into account exactly what kind of demands will be made from the battery.

You can use general criteria like cost and weight to narrow down your initial choices. If low cost is really essential, that tends to rule out the NiMH and Li-ion batteries for a start. Or conversely if it's important to achieve the highest possible battery capacity in the smallest size and weight, with the cost of no great concern, that will tend to rule out the SLA, RAM and NiCad batteries.

The final choice will depend upon things like the kind of discharge-recharge cycling that will be involved, the voltage regulation expected from the battery, the time available for recharging when it's discharged, how much access and effort can be provided for battery housekeeping, and so on.

The comparison chart and discharge curves given on the earlier pages should help you in making this decision.