Electronics for Model Railways

Chapter 8

Batteries

By Davy Dick

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By Davy Dick

In memory of Margaret

Contents

Batteries

Most model railways use mains power packs to control trains and accessories.
However, batteries still play a big role in our everyday lives (think TV remotes, tablets, smoke and carbon monoxide detectors, torches, your car, etc.)
In the model railway world they can be found in:

- Radio controlled locos
- Test equipment
- Coach lighting

Batteries are electrochemical devices that store electrical energy in the form of chemical energy. When attached to a circuit, they convert the chemical energy back into electrical energy.
A battery is made up of three parts:

- The anode
- the cathode
- the electrolyte

The current flows from cathode to anode (electrons are negatively charged and are attracted to a positive charge). Electron current describes the actual process, while early pioneers thought that current flowed from positive to negative (called *'conventional current'*).

Making comparisons

Batteries are available in a huge range of sizes (from hearing aid battery to lorry battery), voltages, capacities and material construction.
The performance of each type varies so here are some comparisons.

Size, shape and weight

These considerations are very important for model railway coaches and for portable equipment such as hand-held devices.
Due to the different manufacturing methods and materials, the same battery shape may have many descriptions. For example, the common AA battery may be found labelled as U12, HP7, Penlight, MN1500, MX1500, LR6, R6, FR6, or 15LF.
Similarly, AAAA, AAA, C, D and 9V batteries have alternative names.
Rather than name them all here, you will find the details at:

https://en.wikipedia.org/wiki/Battery_nomenclature
http://www.batteriesandbutter.com/standard_battery_size_chart.htm

The dimensions for the most common batteries are:

AAAA	L 42mm, D 8mm
AAA	L 44.5mm, D 10.5mm
AA	L 50 mm, D 14.2mm
C	L 46mm, D 26mm
D	L 58mm, D 33mm
9V / PP3	H 48.5mm, L 26.5mm, W 17.5mm

Where L is the length, D is the diameter, H is the height and W is the width.

For even smaller sizes, some batteries are available in *'coin'* or *'button'* shapes. A coin cell resembles a coin (flat and thin), while a button cell has a smaller height than its diameter. Button cells tend to be 1.5V alkaline or 1.55V silver oxide, whilst lithium 3V coin cells tend to be much thinner.
They may have 4-digit numbers, the first 2 digits being the diameter in millimetres and the last 2 digits being the height in tenths of millimetres.
So, for example, the commonly used 2032 coin cell is 20mm in diameter and 3.2mm high.
This type is widely used in portable devices such as watches, calculators, car key fobs, digital thermometers, hearing aids, cordless phones, as well as on computer motherboards.

They can be found stacked in a tube to obtain higher voltages.

Pouch cells are lightweight as they have a soft outer shell instead of a metal shell.
This makes them ideal for use in portables devices such as Bluetooth headphones and music players as well as toys and wearable electronics.
This type is mostly used in LiPo batteries (see later).

Capacity

The rated capacity of a battery is the amount of electricity that it can store and produce when fully charged.
It is usually measured in '*Ampere Hours'*. For example, a battery rated at 10Ah should deliver 10A for 1 hour or 2A for 5 hours, and so on.
For electronic equipment, the current demands are often quite low and so their demands are measured in mAh (milliampere hours).
Here are some typical capacities of popular alkaline batteries:

Battery Type	Capacity (mAh)
AAA	1000
AA	2400
C	6000
D	13000
9 Volt / PP3	500

These figures are a guide, as they vary by manufacturer, by product and by usage (e.g. temperature, current drain, etc.).

Power delivery

One of the reasons for different battery technologies is to provide options for power delivery. Some projects want to be fed a low current for a long time (e.g. a watch or a hearing aid) while others will demand a high current but for a short time (e.g. a car starter motor).
The power capability rating is known a C value and is a multiple of its rated capacity. The rating measures how fast you can safely discharge a battery.
For example, a 1Ah battery with 0.1 capability rating cannot supply 1A for an hour; the best it can do is supply 100mA.

Alkaline batteries have a C rating of around 0.1C, while lithium batteries designed for watches have a C rating of just 0.01C.
At the other end of the scale, lead acid batteries have a high C rating of around 10C. This is needed to produce hundreds of amps to turn over your car engine. For example, a 40Ah battery with a C rating of 10 can produce 400A

Example

This Li-Po battery pack has a capacity of 1500mAh and a C rating of 35. That means it can produce a maximum of 1,500mA x 35 = 52A for a short period of around 2 minutes or 15A for around 6 minutes.
It is designed for fitting in radio controlled cars and drones that have powerful motors but are operated for short periods.

There are two other measures of a battery's performance

- Energy density
- Power density (or specific energy)

Energy density defines how much energy the battery can store for its size.

Power density defines how much energy the battery can output for its size in a given time. Power density is measured in Whr/kg (Watt hours per kilogram of weight).

Examples

- Batteries have a higher energy density than capacitors (they can store more energy). Capacitors have a higher power density than batteries (they can deliver greater amounts of energy in a shorter time. Try operating a point's solenoid with a battery rather than a fully-charged capacitor to see the difference.
- With their higher energy density, batteries can provide continuous low current levels for longer periods than capacitors, including supercapacitors. That's why we use capacitors to provide flicker-free lighting from track pickups in coaches for short periods but use batteries for continuous lighting.

It is common for publications to treat the two properties as being identical, with battery output properties being described as energy density.

Here are some typical power density values, in Wh/kg, for different battery types.

Carbon Zinc	36
Alkaline	130
Lead acid	30-50
Ni-Cd	45-80
NiMh	60-120
Li-ion	110-160
Li-po	100-130

You choose your battery for your purpose depending on its size, capacity and power delivery.
You already choose different types for your watch, your TV remote, etc.

Battery options

They may have different material construction but they all fall under two main categories:

- Disposable (also known a s primary batteries)
- Rechargeable (also known as secondary batteries)

Disposable batteries

Sometimes called primary batteries, these are non-rechargeable and disposable.
The electrochemical reactions inside the battery are irreversible.

Carbon Zinc

This was the earliest of the regular disposable batteries.
Also known as Zinc Carbon, they provide 1.5V per cell.
They are available in a variety of shapes (AAA, AA, C, D, 9V but not in coin or button).
The 9V PP3 version contains six individual 1.5V cells.
They are regarded as a low cost alternative to alkaline batteries but they perform less well.
They have a lower energy density than alkaline batteries, a shorter shelf life and more prone to temperature extremes.
With a poor discharge rate performance they are most suited to current drain devices such as radios, remote controls, clocks, toys and low power torches.

Zinc Chloride

These use a different chemical composition that provides them with twice the power density of carbon zinc.
They are often described as heavy duty batteries.
Although available as AAA, AAA and 9V, they are more commonly

found in larger sizes, such as Type C and D and lanterns.
They are not available in button or coin sizes.
They too are composed of 1.5V cells.
The use of purer chemicals gives them around twice the service life of a carbon zinc battery, longer shelf life and improved temperature performance.

Zinc-air

These batteries use oxygen as one of their main components. The tab on a new button battery is removed to reveal tiny holes in the case that allows oxygen to be derived form the atmosphere. This reduces the weight and size of the battery The one shown here is a ZA312 / PR41 and is 7.93mm diameter and 3.5mm in height. They contain no toxic ingredients.

The cell is 1.4V with a capacity of 175mAh and is ideal for hearing aids or watches.

Alkaline

This is the most popular disposable battery.
It is available in the same range of sizes as zinc batteries (AAAA, AAA, AA, C, D and 9V), plus coin cells (e.g. 2032) and button cells (like the LR41 shown here).

The 23A type is 28mm height and 10.12mm diameter.
They are mostly rated at 1.5V, apart from some coin batteries that are rated at 3V and the 23A which is a 12V battery.
The 9V PP3 version contains six individual 1.5V cells.
Alkaline batteries offer the following:

- Higher capacity than zinc batteries (three to five times greater).
- Higher power density than zinc, providing a higher current output .
- Stable performance at temperature extremes.
- A low self-discharge rate, only losing up to 5% of capacity per year, resulting in a long shelf life.

Alkaline batteries are ideal for low current applications and are used in many consumer devices like TV remotes, calculators, wall clocks, torches, and toys. The main problem with them is there tendency to leak after a while, with the resultant corrosion of their holders.
The 12V 23A batteries have low capacities (e,g, the one from GP is only 38mAh) and are found in low usage situations such as doorbell push buttons and remote control key fobs for garage doors.

Silver Oxide

These batteries are designed for low current, long-term use applications such as watches and hearing aids.
They are only produced in button sizes and are 1.55V per cell.
The amount of silver used is low so they are not particularly expensive.
They have a very high energy density and can offer up to 5 years of shelf life.

Lithium based

These are primary batteries, not to be confused with Lithium Ion which is a rechargeable battery. The term '*lithium battery*' refers to a range of different material compositions, the common feature being the use of lithium for the battery's anode.
They offer many improvements on previous technologies:

- They offer a range of voltages (1.5V, 3V, 3.6V, 9V).
- They have a high energy storage density and high power density.
- They are available in low capacity to very high capacity.
- The output voltage remains constant during discharge
- They weigh 30% less than alkaline batteries.
- Low self-discharge (the loss of capacity is only about 0.5% per year) giving them a very long shelf life of up to 10 years (Energizer claim up to 20 years).
- Leak resistant (Energizer guarantee them to be leak-proof, based on standard use).
- They can perform in extreme temperatures (from -40C to +60C) making them useful in outdoor applications..

Although much better, they can be considerably more expensive than alkaline batteries.

Lithium examples

These are available in 1.5v, 3V and 3.6V versions.
They are most available as coin cells, with a couple of exceptions.

- The CR1216 battery is a 3V coin cell (12.5mm diameter, 1.6mm height) with a capacity of just 25mAh.
- The Energizer L92 is a 1.5V battery in AAA shape with a capacity of 1250mAh.
- The Tadiran TLH-5955 is a 3.6V battery (14.5mm diameter, 33.5mm height) with a huge capacity of 1.4Ah.

Lithium Manganese Dioxide

Also described as $LiMnO_2$, this is the more common of the lithium group of batteries.
It uses manganese as its cathode and lithium as its anode.
They are available in voltages ranging from 3V to 9V.
They are mostly produced as coin cells and AAs, with notable exceptions.

The ANSMANN CR1216 is a coin cell battery with a capacity of just 24mAh.

Here is the Ultralife U9VL-J-P 9V PP3 1.2Ah 150mA continuous
Note that it is confusingly badged as *"Lithium"* although it is in fact a Lithium Manganese Dioxide battery.

The Panasonic CR123 is a 3V battery with dimensions of 34.5mm high and 17mm diameter and a large capacity of 1.4Ah.

This is the Varta 6117101301 3V battery in AA format and an even larger capacity of 2Ah.
Note that it also simply badged as *'Lithium'*.

This is the Duracell DLCR-V3 3V battery with a rectangular shape (52.2mm height, 28.6 width, 14.6mm depth) with a huge 3 Ah capacity.

Uses

Lithium disposable batteries can be found in many devices.

- Coin cells are used in devices such as computer CMOS backup, car key fobs, 3D glasses, some watches (including FitBits) and kitchen scales.
- Their long life makes them popular in computer backup, electricity, gas and water meters, wireless alarm systems, PIR sensors, fire alarms, smoke alarms, pacemakers, security devices, etc.
- Their high power density makes them popular for MP3 players, game controllers, digital cameras, radios, toys, high power torches
- Their leak resistance makes them popular for use in unattended locations.

Note

Lithium batteries don't respond well to being mishandled. Check out:
https://www.youtube.com/watch?v=zqV6zEO7hEQ

Rechargeable batteries

These are also known as *'secondary'* batteries. They are more expensive than disposable batteries but are cheaper in long run as they can be recharged many hundreds of times, depending on their chemical composition (see later).
You are never left short of a battery. However, you may need to recharge a low battery.
Rechargeable cells have a worse self-discharge rate, specially nickel-based types (Ni-Cd and NiMh) which can lose as much as 15% of their charge per month. These batteries are never fully charged unless they are keep on a constant trickle charge.
Lithium-ion batteries perform better than nickel-based, with up to 2% loss per month. This is still considerably worse than alkaline disposables.
The capacity of nickel-based batteries also tend to be less than that of alkaline disposables.

Lead acid

We are familiar with the heavy batteries in our cars but they don't exactly fit in our N gauge coaches!
Nevertheless, we can find uses for them.
Of course, they are heavy devices.

Even this modest 12V 7Ah Pro Elec battery weighs over 2kg.

At the other end of the scale, you can buy a Varta 230Ah model that weighs in at a hefty 57kg.

All modern lead acid batteries are SLA (Sealed Lead Acid), removing the need to unscrew individual vent caps to top up each cell. The sulphuric acid electrolyte is thickened so it cannot spill out. They are usually marketed as *'maintenance free'* and many offer a 5 year guarantee. Sealed batteries also eliminate acid spills, corrosion of terminals, fumes, etc.
They are not environmental friendly to manufacture (consumes much more raw material than Li-Ion for the same energy storage) but are easy to recycle.
They are based on 2V cells so are available in 2V, 6V, 12V and 24V versions.
They have low energy density but are capable of high discharge rates (think starting your car).

They are of use where size and weight are not important considerations.
Examples are hospital equipment, mobility scooters, emergency lighting and UPS (Uninterruptible Power Supply) systems.
The smaller sizes are used in alarm systems and emergency lighting systems.
Uses for modellers include:

- Standby if layout power fails
- No nearby power source (e.g. garden)
- On board large locos and models (e.g. the 6V version is used in model boats)

Ni-Cd

Ni-Cd batteries, also described as NiCad, are one of early lightweight rechargeables.

It uses nickel oxide hydroxide for its cathode and cadmium for its anode.

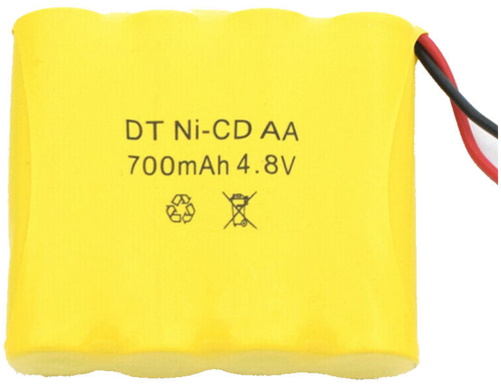
Since cadmium is a toxic heavy metal, it is harmful to the environment and Ni-Cd has continually lost ground to NimH batteries.

An individual Ni-Cd cell is rated at 1.2V and they are available in various sizes (buttons, AA, Sub-C).

The Sub-C shown here is 43mm length, 23mm diameter. It has a capacity of 1200mAh.

They are assembled into multi-packs to achieve higher voltages.

This is the image of a 2.4V button pack with 60mAh capacity.



This pack contains four cells to achieve a voltage of 4.8V, with a capacity of 700mAh.

Similarly, a pack of five produces a 6V battery and a pack of ten produces a 12V battery.

They were not always suitable as replacement in devices that used 1.5V batteries. For example, a device that used four 1.5V cells would be using four 1.2V cells. Using 4.8V in a 6V device did not always allow the device to function successfully.

Ni-Cd batteries have low internal resistance and this means that they can deliver high currents. The voltage also stays relatively constant during discharge.

They were used in portable power tools, emergency lighting, and handheld devices such as torches and handheld games.

The trend is to use NimH batteries instead of Ni-Cd.

NiMh

Nickel Metal Hydride is a more modern battery and has many advantages over Ni-Cd batteries.

The anode is nickel hydroxide and the cathode is metal hydride. NiMh contains no toxic metals and is more environmentally friendly than Ni-Cd.

It has a higher capacity and a higher energy density (more energy for its size).

It is composed of 1.2V cells.

They are available in button versions as shown, many with tags.

Like Ni-Cds, they can be packed to produce higher voltages.

They are also available in AAA, AA, C and D sizes.

Here is a D battery with a capacity of 10,000mAh, i.e. 10Ah.

When produced in packs, they available in a variety of voltages and shapes.
There is a 2.4V version for baby monitors.
There is a 3.6V versions for razors.

This is the image of 4.8V pack with a capacity of 5000mAh.
It is sold as a *'Racing Battery',* intended for model racing cars.
There is also a 7.2V version for this purpose.

They are used in electric toothbrushes, digital cameras and cordless phones.
Their relatively light weight (in comparison) and ability to deliver bursts of high current is fully exploited.
They are also to be found in the removable packs for powering hand held devices such as cordless drills and hedge trimmers.
The voltage also stays relatively constant during discharge.

Unfortunately, their self discharge rate can be quite high (as much as 30% per month).

Lithium rechargeables

These rechargeable batteries, like their disposable versions, use lithium in their construction.
There are two main types:

- Lithium-Ion (Li-Ion)
- Lithium Polymer (Li-Po or LiPo)

The main difference is that the Li-Ion has a liquid electrolyte, whereas the Li-Po uses a gel-like polymer.

Lithium ion

Li-Ion cells have the highest energy density (more usage time for the same weight).
They are also cheaper than Li-Po batteries.
However, as the cell's electrolyte is liquid, they use a solid aluminium casing, This makes them heavier than Li-Pos.
The cell voltage is normally 3.6V or 3.7v, depending on the chemical makeup.
They operate over temperatures ranging from -20º C to 60º C and have a self-discharge rate of up to 3% per month.
Most, but not all, Li-Ion cells have an internal circuit to regulate current, as they can be volatile if misused.   This includes overheating, catching fire, or even exploding!   For that reason, Li-Ion cells must be charged with a specially designed charger.
Nevertheless, they are in widespread use.

Lithium Ion cells are produced in a variety of sizes and shapes.

Coin cell

This is the LIR1220 coin cell.
It has a high energy density and a capacity between 6mAh and 12mAh.
It is used in high-tech applications like wearables, Bluetooth headsets, medical devices, remote controls, toys, and more.

Note

> Some coin cell batteries are advertised as Li-Ion but a close look at their labels or packaging shows them to be normal Lithium disposables.

AAA and AA

There is no widespread Li-Ion equivalents for AAA and AA cells.
The Li-Ion 10449 cell is the nearest in size to AAA, while the 14500 closest to the AA cell.
They are not intended as drop-in replacements, plus they are not 1.5V cells.
A few companies have developed AAA and AA equivalents.

They are manufactured in AA and AA sized cases and have electronic circuits integrated into them that steps the voltage down 1.5V. As yet, no major companies have produced these 1.5V versions.

18650

The most popular Li-Ion cell is the 18650 (i.e. it is 18mm in diameter and 65mm in height).
The Panasonic NCR18650B has a capacity of 3200mAh and a power density of 243Wh/kg.
This performance is widely used both as single cells and in packs of cells.

Here, a single cell is used to power this super bright 1150 lumen so-called *'tactical LED torch'*.

When assembled as packs of multiple 18650s, they are used in laptops and notebooks, toys, lighting, cordless tools, and in electric and hybrid vehicles.

For example, a pack of three 1.7V cells gives 11.1V.

This DeWalt pack uses five 3.6V cells to produce an 18V plug-in power pack.

Most batteries have contacts and are designed to insert into holders.

This is a battery for a Samsung Galaxy.

Others have trailing leads and have to be soldered into a circuit.

PS – An unused laptop battery is a good source of 18650 cells.

Lithium Polymer

Lithium polymer batteries have 3.7V cells and are also described as LiPo, Li-Po, Li-Poly, Li-Polymer, or Lithium-Poly.
Since they have no liquid electrolyte, there is no need for a metal protective metal case. Instead, they use lightweight aluminium foil, possibly surrounded by heat shrink tubing. This makes them the lightest of batteries and very useful where weight is particularly important. It also makes them more prone to physical damage and some LiPo batteries use hard plastic cases.
The lack of a liquid electrolyte also means that there is little chance of leakage.
They are safer to use and more environmentally friendly than Li-Ion batteries.
However, they more expensive than Li-Ion batteries (the current estimated cost is around 30% greater) and have shorter life spans.

They store twice the energy of nickel-based batteries and four times that of lead acid batteries, but have lower energy density than lithium-ion batteries.

Their main quality is their very high power density.
They a have a low internal resistance and gives them a high discharge rate performance. This is given as a 'C' rating, being the maximum current the pack can safely draw, given as the multiplication factor of its capacity.

For example, this battery has a capacity of 650mAh and a C rating of 20.
That means the battery can output

20 x 650 = 13,000mAh = 13A

on a continuous basis, until it is exhausted.
Note also that it has a JST connector for a plug-in connection - a crimped connection that is a standard for radio control models.

This battery, although having a lower capacity of just 180mAh, has a C rating of 45.
That means the battery can output

45 x 180 = 81,000mAh = 8.1A

on a continuous basis.

Other LiPo batteries have a C rating of 65C and a burst rating of 135C.

Packs

Cells are wired in series to achieve higher voltages.
A LiPo battery has an 'S' rating which is the number of cells in the pack,
The one shown here, for example, is a 3S pack. Its three cells combine for an output voltage of 11.1V.
With a C rating of 35, it can supply a continuous current of 1500 x 35 = 52.5A

Of course, these very high currents are often not required for long periods, mostly being used for sudden accelerations. Running at half the C rating results in more recharge cycles.
A 3S2P pack contains two sets of cells connected in parallel, with each set having three cells connected in series.

Uses

Their light weight is put to use in mobile devices such as phones, laptops, notebooks, tablets, radio controlled aeroplanes.

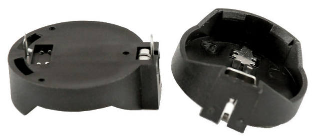
Their high power output is put to use in drones and radio-controlled toys such as cars, boats and aircraft. Their ability to provide short bursts of high power for take-off and acceleration, combined with their light weight, make LiPos the ideal choice. These batteries are the ones that are likely to be encased in a hard shell to protect them from the likely sudden knocks they will experience

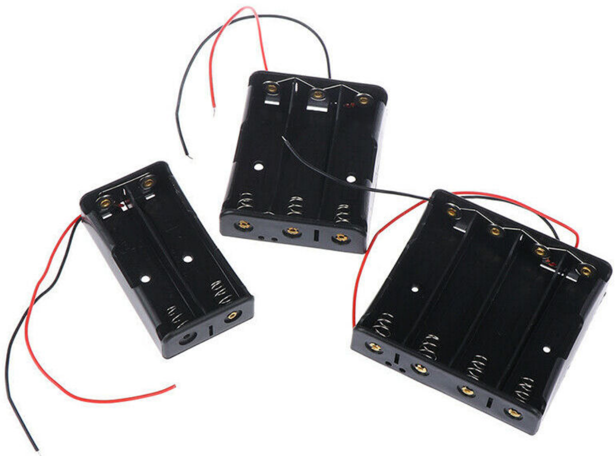
LiPos are not available in coin or button format but there are now AAA and AA versions. They have built-in electronics to scale the 3.7V down 1.5V so that they can be used to replace alkaline and other AAA and AA batteries.
This image shows one even more electronics inside, so that it can be recharged from its USB socket.
Similar batteries are available in C size.

Battery holders

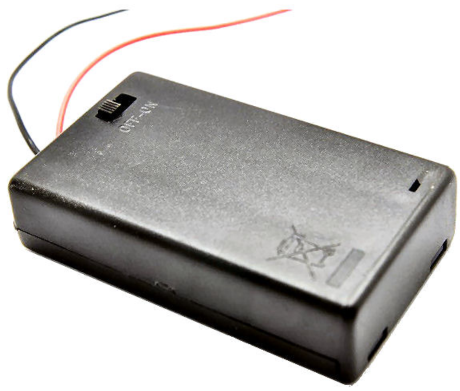
Where space is tight (e.g. inside locos or coaches) you may prefer to solder directly on to a battery's terminals. Some batteries have no terminal contacts and provide leads for soldering.
In most other cases, you will probably use a battery holder, as it allows you to easily replace batteries when necessary. The battery's contacts are pressed against the holder's contacts, often with springs maintaining good electrical contact.

Battery holders are readily available for a range of battery sizes (cell, AAA, AA, C, D, PP3, 18650s).
They are also available as a holder for a single battery or for a set of batteries (2's, 3'3, 4's and 8's).





For example, a holder for a pack of three 18650 batteries provides a powerful substitute for a 12V supply.



A holder with four 18650's makes an ideal power pack for a TS100 soldering iron (a portable, lightweight soldering iron. that operates on a voltage between 12V and 24V).
Both of these packs could be very useful at exhibitions.

You can also purchase a battery holder case complete with on/off switch and leads and these are used with cheap Christmas fairy lights.

Battery Adaptors

These are cases that fit one battery holder but contain a smaller size of battery inside. Examples are;

- Single AAA to AA
- Single AA to C
- Single AA to D
- Two parallel AAs to C
- Two parallel AAs to D

You may have a collection of rechargeable AA batteries and then buy a device that needs a C or a D cell.
Instead of investing in another rechargeable battery size, you can use you existing AAA or AA instead.
You can buys a case that holds a single cell, or holds two in parallel to deliver extra power.

Dummy batteries

These look a normal battery but inside is just a length of wire shorting its anode and cathode contacts. They are useful to convert from using 1.5V alkaline batteries to 1.2V rechargeable batteries.
You may have a device that currently uses four 1.5V alkaline batteries – i.e. it requires 6V to operate. You cannot simply replace them with four 3.7V batteries – 4 x 3.7V = 14.8V which would destroy the device. The solution is to fit two 3.7V batteries and two dummy batteries. This results in 7.2V to the device, which most devices can cope with.
Conversely, you may have a device that is using five 1.2V rechargeable cells to achieve 6V. You could fit four 1.5V alkaline batteries and a dummy battery to also achieve 6V.
Dummy batteries are also available with wires leading out to allow an external supply to power portable equipment while it is ‘on the bench’ for test repair calibration etc.

Battery charging

Unlike an exhausted disposable battery, a rechargeable battery can have its electrochemical reactions reversed. Do not attempt to recharge a disposable battery as this could result in its leakage or even rupture.
It is possible to charge batteries from a bench power supply by adjusting the voltage and current settings in a particular sequence for that particular battery type.
If you are short of cash, you can find suggestions for this on the Internet.
However, it is important to avoid overcharging your battery as this could result in shortening the battery's life or worse.

Intelligent chargers

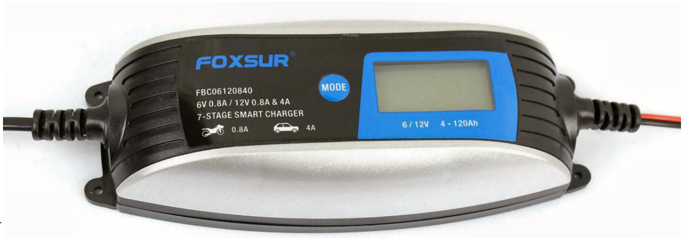
Some Li-Ion cells have inbuilt circuits to prevent high surges of current and any excessive applied voltage. For all other cells, the correct charging process is essential.
Intelligent chargers have electronics that monitor the charging process at every stage and adjust the voltage/current as necessary.
That is why there are different chargers for different types of battery; their charging schedule and settings will differ.

Note

> Don’t use rechargeable batteries in chargers that are not designed for that specific battery type.

Lead acid

Lead acid batteries can withstand fast charge–discharge duty cycles.
Even cheap lead acid battery chargers provide adequate protections such as automatic voltage and current protection and short circuit protection.
Others offer polarity protection (in case you connect the charger's leads in reverse) and even microprocessor controlled charging for optimum charging.
If you wish, you charge a lead acid battery from a bench power supply and calculate the correct voltage and current levels for the battery you are using (Google for details). However, a commercial battery charger is usually reliable and hassle free.



A cheap basic charger will just continually send out a constant voltage (CV) regardless of the current state of the battery.
An intelligent charger uses a CCCV (constant current constant voltage) charging method. The charging current is kept constant until the voltage reaches the correct level. The current then drops away until it is in a trickle charge mode.
You do not need to fully discharge a lead-acid battery before recharging it, as it does not exhibit a 'memory effect'.
It lasts last longer if it is topped-up regularly, instead of fully draining and fully charging it.
Batteries should not be stored in a discharged condition. If the cell voltage drops below 2.10V, the cell's plates are damaged, possibly irreparably. So, if a battery is to be stored for a long period, it should be at least part-charged.

Ni-Cd and NiMh

Unlike lead acid cells, nickel-based cells are charged using a constant current (CC) source.
A constant voltage source would result in excessive current and cell damage, as their internal resistance is low.
There are two main considerations:

- Knowing what current level to charge at
- Knowing when to stop charging

While lead acid batteries can handle large variations in voltage and current, nickel-based cells charge with a steady current and slight voltage variations.
Ni-Cd batteries are often charged at C/10. For example, a 2Ahr battery would be charged at 200mA. It will take slightly longer than the calculated 10 hour charging time as some of the energy will be converted into heat. Fast charging can be carried out at C/1, C/2 or C/3.
An intelligent Ni-Cd charger can operate at a high C rating until the battery is about 70% charged, before dropping down to trickle charges at around 0.02C to 0.1C

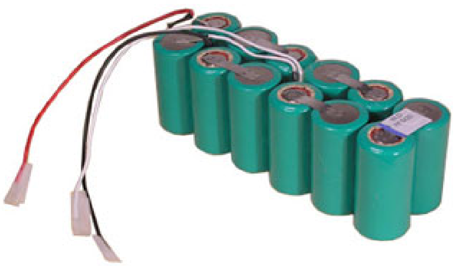
The difference between Ni-Cd and NiMh cells lies in the way the charge reduces after the main charging has been achieved. Most Ni-Cd cells can handle an indefinite charging current of C/10 without any damage to the cell. This is not the case with NiMh cells which are which are prone to damage from overcharging.

Note

NiMh and Ni-Cd charges use different algorithms, so don't use Ni-Cd charger for NiMh batteries. NiMh chargers can happily handle Ni-Cd batteries. Some chargers handle both battery systems.

The difference between the two cell types lies in they way they change as they approach full charge after a steady voltage increase.. At around 70% of full charge, both cells exhibit a small drop in voltage and more of the charging energy is expended as heat. With Ni-Cd cells, the drop is more pronounced than NiMh cells.
As the battery continues to charge, more and more energy is dissipated as heat.
A Ni-Cd charger will detect the voltage drop and reduce its charging rate. However, if a NiMh battery is charger with a Ni-Cd charger, the electronics will not detect the smaller voltage drop and continue charging at the higher rate.
A charger that is designed to charge both types of cell understands these differences and acts accordingly. Beware, however, that cheaper chargers that claim to handle both may in reality act just as a normal Ni-Cd charger.

Some chargers adopt another monitoring technique. Instead of only detecting voltage changes, they detect the rate of temperature change of the battery. The temperature of the cell can more accurately reflect the current state of charge. Some large battery packs have an extra connector that links their internal temperature sensor with a charger that supports temperature sensing.



Trickle charging

This is designed to keep batteries at their full voltage, so that they are always available for use. Trickle charging replenishes any losses that would occur with self-discharge if left in storage. However, constant trickle charging is not recommenced as it can reduce their life span. Recharging the battery before use, although not as convenient, is a better approach.
Batteries should not rise about the ambient room temperature during trickle charging. If they do, the trickle charge rate may be too high for the battery.

Li-Ion

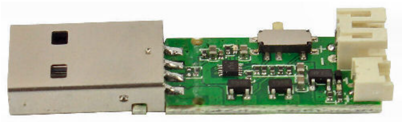
Li-Ion charging uses the (Constant Current, Constant Voltage) method.
These batteries are often initially charged at 0.5C or 1C, with a constant current source.
During this initial stage, the charging current remains constant while the battery voltage constantly rises.

When the cell's voltage reaches 4.2V, it is instead fed with a constant voltage to stop overcharging. During this second stage, the voltage remains constant and the current demand drops away until it reaches around 0.1C.
A Li-Ion charger monitors the charging progress and decides when to change from the CC stage to the CV stage.

Given its special charging phases, you should only use a charger that is designed for Li-Ion Li-Ion batteries.
Some chargers have a USB cable to charge the cells from a USB power source. Don't risk plugging one of these into your computer's USB socket. It would struggle to even meet the needs of a single cell being charged. Instead, connect it to a dedicated charging port that can handle the maximum current needs if all four cells were in charge.

LiPo

LiPo batteries also use the CCCV charging method.
The difference is that the charging process must not be allowed to continue after the battery reaches full charge. Otherwise the cell will still allow current to flow, overheating it, bloating the envelope and finally exploding.
That is why you must only use a LiPo charger to charge LiPo batteries.



This is a simple charger for a single LiPo cell. You plug the cell into the charger then insert the USB plug into a 5V source.

LiPo are mostly charged at 1C.

Some cell packs are designed for fast charge
This one has a discharge rating of 25C.
It also has a charge rating of 5C (i.e. you can charge the battery at five times it mAh rating.
Since this one is 5000mAh model, it can be charged at a whopping 25A.

LiPo batteries are commonly sold in packs of cells. They are as 1S, 2S, etc. with the number appearing before the letter S being the number of cells in the pack.
For example, a S3 pack would have three cells, delivering a voltage of 3 x 3.7V = 11.1V.

This image shows the HobbyStar 5200mAh 8S.
Its eight cells deliver an output voltage of 29.6V.
Its theoretical max current is 45 x 5.2A = 234A.
Its theoretical max power is 29.6V x 234A = 6.9kW.

The cells will heat up during charging and it is best to wait until it cools before using it.
Similarly, it is best to only charge the cells when they are cool.

Charging cell packs is a bit more complicated than with single cells.
The cells in a pack are all wired in series with each other and each will probably be at a different stages of discharge. Charging in these circumstances could result in an imbalance of voltages across different cells, with some being overcharged.
To prevent this, cell packs have connections to all batteries to allow for automatic charge balancing. LiPo packs use a JST-XH style balancing lead (white connector). This brings out the interconnections between the batteries, so that the charger knows if one or more cells is not performing as expected under charge.

Of course, the charger being used has to have connections that provide that facility.
This is the SKYRC Ultimate Duo balance charger with the capability of 200W per channel, or 400W if only a single channel is used. You can see the balance ports along the front of the case.

For best results, the charger will monitor the voltage and temperature of every cell in the pack, monitor the overall pack voltage – and close down the charging process should any problem be detected.

Handling batteries

Detecting duds

To be of use, batteries need to have a minimum amount of useful energy left in them, or be capable of being recharged.
It is easy with disposable batteries; you can use a voltmeter to check the actual voltage against the cell's rating. It is best to do this with the battery connected to its usual load.

Rechargeable batteries are different.

- You may be able to tell by visual inspection (leakage, cracks, expansion of the container).
- You may be able to tell by reading the cell's current voltage. Li-Ion cells at below about 2.5V and LiPo cells below 3V probably indicates that they irrecoverable. On the other hand, Ni-Cd cells can be discharged to very low levels and be fully recharged.
- The best determining factors is whether the cell is able to maintain its charge after recharging. Any rechargeable battery that is unable to hold its charge is usually spent. You can recharge the battery, use it in a device for a while and then check its voltage (preferably something like an incandescent lamp rather than your expensive equipment). If the voltage has dropped substantially, the battery is useless.
- If a cell just keeps getting hotter rather than charging.
- A smart charger will have indicator LEDs that show whether a cell is charging properly.
- A commercial battery tester, like the ones shown here, can display the total voltage of a battery pack, voltages of individual cells, remaining battery capacity, etc.

Storage

- Remove batteries from devices that are not used regularly or are being stored for an extended period.
- Store batteries at room temperature, or cooler, in a dry atmosphere and away from direct sunlight.
- If you have multiple batteries, it is best to cycle your way through them periodically, rather than letting some lie unused for long periods.
- If you have purchased new batteries, keep them in their original sealed packaging until you want to use them. This helps protect them from any humidity.
- Store batteries in a secure container, away from children and pets . Coin-cells batteries are a particular choking hazard.
- Store lead acid batteries at full charge, Li-Ion at around 50% and NimH and Ni-Cd at any charge level.
- Some people recommend storing batteries in their fridge. It will provide a minor improvement in charge retention but only if they are in a sealed container to avoid condensation or water damage.

Usage

Charging batteries

Charge batteries in a safe place to avoid damage if a cell should suddenly explode or ignite. This may be outdoors or inside a fire-retardent battery bag like the one shown here. In any event, you should never leave batteries unattended while they are charging.
For the same reason, do not charge batteries near flammable items or liquids.
Most devices that use Li-Po batteries expect the batteries to be charged in situ.
To avoid potential damage to the device, it is best to charge the battery away from the device if possible.

Handling batteries

There is always a danger of unintended short between batteries.

- Don't leave batteries on a conductive surface, such as a metal tray or anti-static mat.
- Don't carry batteries around loose in your pocket. They could short to each other or to your keys, or to loose change. The same applies to leaving them loose in a bag or a drawer.

When working on your bench, make sure that batteries are free from the possibility of accidental puncture (e.g. from a drill or a hobby knife). In the event of a leak of electrolyte on to your skin, thoroughly wash it with soap and water.

If you are building a module that might be used by children, fit an enclosed battery compartment, particularly one with a screwed lid or cover.

Battery disposal

When you find yourself with exhausted batteries, remove them from the device before they leak or cause other accidental damage.
Don't throw them in the waste bin or on a bonfire. Don't attempt to dismantle them.
If they still have some charge left, discharge the remaining energy.
Don't short-circuit batteries to discharge them – use a load to dissipate the energy.
Here is good advice from the Greater Manchester Combined Authority:

> *"Batteries should not be placed into any household waste or recycling bin as all of them have the potential to spark. Collection vehicles can damage and bend batteries, releasing some hazardous chemicals and energy, potentially causing an internal short circuit. Other materials in your bin, in particular paper and plastic, can spread a fire.*
> *It's simple and free to recycle regular household batteries. You can take them to your local Household Waste and Recycling Centre. Or you can take them when you go shopping and drop them off at designated containers located near the checkouts or exits at most local supermarkets."*

Finally, here are some websites with more information on batteries:

/www.ti.com/lit/an/snva557/snva557.pdf

https://batteryuniversity.com/learn/

/www.mpoweruk.com/life.htm

www.youtube.com/watch?v=5Q1MPrgea1M