The Gibbs Guide to

Nickel Metal Hydride & Nickel Cadmium Batteries

A Gibbs Guides e-book

By

Andrew Gibbs

gibbsguides.com
Messages from Andrew Gibbs

Thank you for purchasing this e-book to Hydride and Nicad batteries. I sincerely hope it will be an enjoyable read, and that it will be a great deal of help to you. If you like the guide, please tell your modelling friends. If you have suggestions for improvements or alterations, please feel free to contact me.

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Andrew Gibbs

Cover photograph

The cover photograph shows Martin Hardy’s magnificent 96in span HP42. This model was designed some years ago, and was originally intended for nicad batteries, although Martin’s beautiful creation uses modern lithium batteries.
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The Hydride and Nicad batteries used in modelling should be supplied with instructions. If not, then information about the product should be obtained from your retailer and/or the manufacturer. You are strongly encouraged to read and implement any such instructions, especially those instructions relating to safety. Such instructions must be accurately followed without deviation. None of the information within this guide is intended to overrule any such instructions, and where any disagreement exists, always follow the instructions of the manufacturer and contact them or the supplier of your equipment for advice about the particular circumstances of your application.

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Preface

Almost every modeller uses nickel metal hydride (or just hydride for short) batteries in one piece of equipment or another. Although there is a trend towards Lithium Polymer (usually shortened to lithium or just lipo) batteries for transmitter and receiver flight packs, the vast majority of modellers are still using hydride batteries in transmitters at least.

There are still quite a number of nickel cadmium (nicad) batteries in use, although these are not normally available to purchase any longer due to environmental concerns about the toxicity of cadmium. The characteristics of nicads are very similar to hydrides, so this guide can conveniently cover both types.

Hydride and nicad batteries were formerly in common use as flight packs for model aircraft, although most models now use the lighter lithium batteries. Nevertheless, there are still a number of models using hydride and nicad batteries which provide enjoyable flying for their owners, so this application is not overlooked in this revised guide.

Whatever the application, any modeller who uses these batteries should find this guide helpful in getting the best from them. Much of the information supplied here also applies to the multitude of rechargeable battery-powered products in common usage such as power tools, torches and so on.

While writing this updated, expanded and revised guide, I have kept firmly in mind that the purpose of our wonderful hobby is enjoyment; for this reason I have tried to strike a balance so that the guide is technically informative while still remaining easily digestible.

I hope you will find the guide useful, interesting – and perhaps even entertaining!

Andrew Gibbs
August 2013

Acknowledgements

Grateful thanks are extended to everyone who helped to make this guide a reality. In particular, I’d like to acknowledge the valuable contributions made by Toni Reynaud for his patience and most excellent charts as well as George Worley of 4-Max.co.uk, for both proof reading and for sharing his technical expertise.
Chapter 1
Battery Basics

What is a battery?
A battery is simply a ‘chemical machine’ for storing electrical energy. The term battery is generally taken to mean two or more individual electric cells. There are two basic types of cell; primary and secondary. Primary cells, such as ordinary ‘dry’ cells, are not rechargeable and must be discarded when exhausted. Secondary cells, such as the nickel metal hydride (NiMH), nickel cadmium (NiCd), lead acid (Pb) and lithium-polymer (lipo) type are rechargeable.

The most familiar form of secondary battery is probably the standard 12 Volt Lead-acid car battery. This takes the form of a plastic tub, sub-divided into 6 individual compartments or cells, each cell producing 2 Volts. Within each cell a number of lead plates are suspended in an electrically conductive fluid, called an electrolyte, which in this case is diluted sulphuric acid. A chemical reaction between the metal (lead) and the electrolyte (acid) generates a voltage. The voltage generated depends on the particular combination of the materials chosen.

Left: The voltage produced by a battery depends on the combination of materials used. This is a four cell Nickel Metal Hydride battery. Each of the four cells produces 1.2 Volts, for a total of 4.8 Volts. Right: Four of the six individual cell of this 12 Volt lead acid automotive battery are seen here.

A brief explanation of electricity
Many of us find the principles of electricity something of a mystery. Fortunately, those used in a modelling context are quite simple to learn, so let’s first recap on a few electrical terms. As you progress through this guide, you may find it useful to refer back to this section as the need arises. To help explain these terms, we can liken the behaviour of electricity to that of water.

Voltage (Unit: Volts; V)
Voltage is equivalent to ‘electrical pressure’ and can be likened to the pressure in a water tank (see diagram below). With the tank filled to point a, the resulting head of water could represent 2 Volts of electrical pressure at the outlet pipe. A full tank, with a greater head of water, would then represent a higher pressure of 12 Volts; a practical example of this is the car battery where six 2 Volt cells are joined internally to form the familiar 12 Volt battery. Voltage is also sometimes called electrical ‘potential’ – because voltage represents the potential for a current to flow, provided a circuit is completed.

This tank of water serves to illustrate the concept of electrical voltage, which can be likened to water pressure. The higher the water level is, the greater the pressure of water (voltage) within the tank.

The tank’s diameter also represents capacity, the flow of water represents current in Amps and the size of the outlet pipe represents electrical resistance – the smaller the diameter, the greater the resistance.

Current (Unit of measurement: Amps; A)
Electric current is measured in Amperes (A), or Amps for short. Current may be likened to the quantity of water flowing per hour through the outlet pipe in diagram 1. For example, a flow of 1 gallon (or litre if you like) per hour could represent 1 Amp. If the outlet pipe was larger, and the increased amount of two gallons (or litres) per hour flowed through the pipe, this would represent 2 Amps.

Currents smaller than 1 Amp are usually referred to in terms of milliamps (mA; 1mA = 1/1000 Amp), for example 0.5 Amps = 500mA. Please note that the water analogy is offered here to help understand the concepts and differences of voltage and current. In reality a complete electric circuit must of course be formed for electricity to flow.

Electrical resistance (Unit of measurement: Ohm; Ω)
All electrically conductive materials have some electrical resistance. This may be likened to the resistance that the water experiences when flowing through the outlet pipe in the diagram above; a small pipe will have more resistance than a large one. Similarly, a thick piece of wire will have a lower electrical resistance than a thin one. This is why thick wire is used for high-current applications such as electric flight battery packs, while thinner wire is used for low current applications, e.g. servo wires. Resistance is measured in a strange sounding unit called the Ohm, often abbreviated to the Greek symbol Ω. A resistance of 6 Ohms may be written 6Ω, or occasionally as 6R (the R standing for Resistance in Ohms).

Internal resistance
The materials from which a battery is made all have their own electrical resistance. We call the electrical resistance of a cell its internal resistance. This factor is a major influence in determining how suitable a battery is for high currents.
Electric circuit
Electric current is said to flow from positive to negative. In order for a current to flow, a complete electrical circuit must be formed.

Power (Unit of measurement: Watts; W)
Electrical power is commonly measured in Watts. One horsepower is equivalent to 746 Watts. The familiar 60 Watt household light bulb therefore consumes a bit less than 1/10 hp. To give some electric modelling examples, an indoor model might consume around 25 Watts, a typical park flyer perhaps 60 Watts, while an average ‘400’-sized model might draw about 150 Watts. By comparison, a 0.40 cu in (6.5cc) glow engine might develop about 0.7Hp, or about 520 Watts while driving a 10x6 propeller. A simple equation tells us how to find the Wattage, or power flowing in a circuit:

\[ \text{Watts (power)} = \text{Volts} \times \text{Amps}. \]

For example, a motor drawing 10 Amps at 8 Volts is consuming 80 Watts of power:

\[ (8 \text{ Volts} \times 10 \text{ Amps} = 80 \text{ Watts}) \]

Off-load and On-load
An electric current is sometimes referred to as a ‘load’. When not being used, a battery is therefore said to be in an ‘off load’ or ‘open circuit’ condition. Similarly, a battery supplying a current is said to be ‘on load’.

Cycle
A cycle is one charge and discharge of a battery (or vice versa). The Cycle life of a cell is the number of cycles it can provide before its performance deteriorates unacceptably.

State of Charge (SOC)
We can refer to the amount of energy remaining in a cell as its ‘state of charge’. For example, a nearly exhausted cell is said to be in a low state of charge. A cell in a low state of charge may also be said to be in a highly discharged state.

Cell Capacity (Ah)
Suppose we have a one gallon water tank. Clearly, this would be able to provide a total volume of flow of one gallon per before it was empty. If the tank took one hour to empty, the rate of flow would be one gallon per hour. We could say the capacity of the tank was 1 gallon-hour, because it could produce a flow of 1 gallon per hour, for one hour.

Similarly, a battery that could provide a current of 1 Amp for 1 hour is said to have a capacity of one Amp-hour, also written ‘1Ah’ or 1,000mAh.

Charging Principles
To charge a rechargeable battery, current is forced ‘backwards’ through the battery (i.e. in the opposite direction to normal) by the charger. This is accomplished by connecting the positive of the battery charger to the positive of the battery, and of course negative to negative. The battery’s own voltage will oppose that of the charger, so the charger’s voltage must be higher than that of the battery. Thus to recharge a 12 Volt battery requires a charger output voltage of perhaps 15 Volts. Recharging causes the chemical
changes that occurred as the battery gave up its charge to be reversed. The recharging process can be likened to connecting a high pressure hose pipe to the outlet pipe of our water reservoir, so that water is forced to flow back into the reservoir.

‘C’ Rate
This is a term used to indicate the amount of current flowing through a battery in relation to its capacity (C). For example, the 1C current for a 1,200mAh cell is 1,200mA or 1.2 Amps. The table below illustrates this concept:

<table>
<thead>
<tr>
<th>Cell Capacity</th>
<th>C/10</th>
<th>1C</th>
<th>2C</th>
<th>10C</th>
<th>20C</th>
</tr>
</thead>
<tbody>
<tr>
<td>600mAh</td>
<td>60mA</td>
<td>600mA</td>
<td>1,200mA (1.2A)</td>
<td>6 A</td>
<td>12 A</td>
</tr>
<tr>
<td>1,200mAh</td>
<td>120mA</td>
<td>1,200mA (1.2A)</td>
<td>2,400mA (2.4A)</td>
<td>12 A</td>
<td>24 A</td>
</tr>
<tr>
<td>2,500mAh</td>
<td>250mA</td>
<td>2,500mA (2.5A)</td>
<td>5,000mA (5.0A)</td>
<td>25 A</td>
<td>50 A</td>
</tr>
</tbody>
</table>

From the table, we can see that 1,200mA is the 1C current for a 1,200mAh battery. Notice that 1,200mA is also the 2C current for the smaller 600mAh battery. So, when using the C concept, we are specifying a current in relation to the capacity of the battery in question, rather than mentioning a specific current. The C rate is therefore a useful indication of how hard a battery is working. For example, a fully charged battery pack would become discharged in about one hour at 1C, or only half this time, 30 minutes if the pack was made to work twice as hard with a discharge rate of 2C.

Note that C rates apply to both charge and discharge currents. It follows therefore that C rates are also a convenient way to describe the ‘speed’ at which a battery is charged. For example, an empty battery charged at a constant 1C would theoretically be charged in an hour.

**Charge rate definitions**
- Fast charge: A current of 1C or above - theoretical charge time of 1 hr or less.
- Quick charge: A charge rate between fast and slow.
- Slow charge: Current of C/10 or less - theoretical charge time of 10 hrs or more.
Chapter 2
Joining cells in Series and Parallel

Series connection of cells.
If two or more cells are joined, positive to negative, they are said to be ‘in series’ and a battery is formed. The voltage of the resulting battery is found by adding the voltages of the individual cells. Any number of cells can be connected this way to provide the required voltage. An example of this is a 4.8V receiver battery, comprising four 1.2 Volt cells. The diagram shows two possible ways to connect 4 such cells in series; end-to-end and side-by-side. The two ways are physically different, but electrically identical.

Clearly, the more cells a battery consists of, the more total energy it will contain. However, because battery capacity is expressed in terms of current and time (e.g. 500mAh), the capacity of a battery is said to be the same as the capacity of the individual cells from which it is made. Thus, the capacity of either of the 4-cell batteries (500mAh cells) shown in the diagram is still 500mAh. The greater energy content of a battery compared to a single cell is reflected by the fact that the battery will deliver the same current for the same time as a single cell, but at a higher voltage and hence at a higher power.

In the same way that individual cells may be joined in series, two (or more) batteries may themselves be joined in series to form a single battery of a higher voltage, equal to the combined voltage of the individual batteries. In this case the cells in both packs should be of the same type and general age/condition. It is most important that before using series-connected batteries that they are each in an equal state of charge. A simple way to ensure this is to fully charge each pack individually before connecting them together. Take great care when connecting batteries in series – it is very easy to unintentionally create a short circuit.

Parallel connection of batteries.
Another way to join cells (or batteries) is in parallel. The capacity of the resulting battery will be the total of the batteries involved, but will be unchanged in voltage - this is the
opposite of series-joined batteries. Cells joined in parallel must be of the same voltage but may safely be of differing capacities. Parallel joining of batteries is shown here mostly for interest because in a modelling context the practice is not normally recommended.

Please note that it might be risky to fast charge parallel-joined nicad or hydride batteries because peak-detect chargers cannot necessarily accurately detect when parallel-joined packs are charged, since a clearly defined voltage peak may not be detected. That said, I have successfully charge a 2-cell parallel pack used in an on-board glow system. If you do decide to charge a parallel joined pack, monitor the charge process carefully with particular regard to the temperature of each of the individual cells comprising the battery. (Note that the commonly used practice of wiring motors in parallel from one battery pack is a different issue, and quite safe.)

Left: This Cougar Fun-fly model built many years ago used a 16-cell nicad battery, plus a brushless motor for power. By modern standards it was heavy, but it was still capable of good performance. Today, LiPo cells would be the usual choice and nicads would not even be considered. Right: The battery bay, showing the heavy load of 16 x Sanyo SCR 1700 nicad cells, all wired in series
Chapter 3
Battery Characteristics

In this chapter we will discuss some of the characteristics of batteries that apply across all types, whatever their chemistry. The specific characteristics of individual battery types are discussed in the relevant chapters.

Battery Voltage

When we refer, for example, to a 4.8 Volt hydride receiver battery, it is important to appreciate this voltage is in fact an approximate or ‘nominal’ voltage. This battery is ‘nominally’ 4.8 Volts, however its actual voltage may be higher or lower than this, depending upon the circumstances. The voltage range of a battery with many cells will of course change more than the voltage of a battery with fewer cells.

A battery, or cell, will always be in one of three states:

1. Off load or ‘open circuit’ – i.e. disconnected from any electrical load.
2. On load – i.e. under discharge
3. Being charged (recharged)

Let’s examine how the voltage of a cell will vary in each of these three states:

1. Battery Voltage in the Off-Load Condition

Let us first consider a cell (or battery) in an ‘off load’ condition. To recap, the battery is in an off-load condition when it is not supplying a current. The voltage of the battery in an off-load condition will vary according to its state of charge. We would correctly expect a fully charged cell to have a relatively high voltage, and an exhausted cell to have a lower voltage.

A note on Internal Resistance

All electrically conductive materials present some resistance to the flow of electricity. This includes the materials from which hydride and nicad batteries are made, such as the metal Nickel. The battery itself, as well as being the source of Voltage in a circuit also has an electrical resistance. The resistance of a battery is known as its internal resistance. Internal resistance has no effect on a cell’s voltage while it is off-load, however in the on-load condition this factor assumes a major importance.

2. Battery Voltage in the On-Load Condition

When a cell (or battery) is on-load, a second factor will affect its voltage, in addition to its state of charge. This second factor is the cell’s own internal resistance. The effect of internal resistance is that when a current starts flowing, the cell’s voltage will be slightly reduced compared to its open circuit voltage and it is said to have suffered a Voltage Drop. The amount of voltage drop will depend on the internal resistance of the cell and the amount of current flowing:

The higher the electrical current (load), the greater this voltage drop will be.
The higher the internal resistance, then the greater the voltage drop will be.
To clarify this important concept, let us now consider some examples:

**Low loads.** A cell of low internal resistance under a very low load will only suffer a very small voltage drop. A cell of higher internal resistance under the same light load will suffer a slightly higher voltage drop. This voltage drop will still be very small if the current is very low.

**Higher loads.** A cell of low internal resistance under a heavy load will suffer a larger voltage drop compared to a lighter load. A cell of higher internal resistance under a heavy load will suffer the greatest voltage drop of all the situations outlined.

All else being equal, the larger a cell is the lower its internal resistance will tend to be. The higher the internal resistance is of a particular cell, the less suitable that cell is for high current applications such as electric power models. Thus, in general, larger cells are better suited for higher currents.

Note that once we stop taking current from a cell, its voltage will begin to rise back to the voltage determined by its state of charge. An important point to remember is that a cell’s internal resistance will only affect its measured voltage when it is on load.

Some practical examples of voltage drop are:

i) In the case of a hydride receiver battery supplying the receiver and servos of a model, when the servos operate, the load they place on the battery will tend to cause the battery voltage to fall. When the servo load is reduced, the voltage will tend to rise again.

ii) When a lead-acid battery is used as the power source for a charger, the voltage drop means the charger will have to operate on a slightly reduced battery voltage.

iii) In the case of an electric powered model, the voltage drop of the flight battery when it is on-load will mean a lower voltage is available at the motor.

*Left:* When a servo moves a control surface, the load which the servo motor places on the battery will cause the battery voltage to fall. *Right:* Similarly, when a charger draws a current from its supply battery, the load which the charger places on the supply battery will cause its voltage to drop.
The graph below illustrates the voltage drop effect that we have just discussed. In this example the off load battery voltage is a six-cell hydride battery, of 7.2 Volts. However, as we can see from the graph, the voltage falls to about 6.5 Volts when the motor is set to half power after 2 seconds. The battery voltage falls a little further, to about 6 Volts when full power is selected at 4 seconds. At 6 seconds the motor is switched off and the battery voltage is seen to rise again towards the off-load voltage of 7.2 Volts.

<table>
<thead>
<tr>
<th>Battery Voltage</th>
<th>Time in Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
</tr>
</tbody>
</table>

3. Battery Voltage under charge
The voltage of a cell under charge will appear to rise. This increase in voltage is mostly because what is actually being seen is the voltage of the charging source. The higher the charge rate, the higher the apparent voltage will be. This characteristic is easily observed using any charger which displays a voltage reading.

The internal resistance of the cell also has some effect on the apparent voltage under charge. The temperature and condition of a battery will also affect its voltage, but for the moment we can overlook these factors.

Battery heating
The internal resistance of a cell is responsible for another characteristic of batteries; their tendency to become warm or even hot in use, depending on the circumstances.

This warming occurs as a natural consequence of an electric current passing through a resistance. The simplest example of this can be seen in an electric fire where the current passing through wire of high resistance causes it to get so hot that it glows. In the case of batteries, any heat generated during discharge will waste some of the cell’s energy and will represent a loss of efficiency. The amount of heat generated will depend on the
internal resistance of the cell and the amount of current flowing (in a similar way to voltage drop):

- The higher the current, the greater the amount of heat generated.
- The higher the internal resistance, the greater the amount of heat generated.

In the case of an electric model, some ventilation must be provided for batteries to prevent cell temperatures becoming too high. Internal resistance also causes cells to have a tendency to become warm during charging, especially during overcharging. We can use a simple formula to calculate the amount of heat generated by a cell’s internal resistance. It says that the heat generated equals the current squared times the resistance. (Heat = I² R) This means that:

1. The heat generated will increase with the ‘square of the current’.

This mathematical-sounding statement simply means that small increases in current will produce disproportionately large increases in the amount of heat generated. The diagram below illustrates this.

For example, if a model draws 10 Amps and we fit a larger propeller to increase the current drawn to about 14 Amps, the heat generated doubles, even though the current has only risen by about 40%. If a still larger prop is fitted so that the current doubles to 20 Amps, the heat generated will become four times what it was at 10 Amps. All the components in a power system will be affected by this ‘law of heat generation’; the diagram therefore shows how it becomes very important to ensure sufficient cooling is provided for cells, controllers and motors at the higher current values.

![Relationship of Heat to Current](image_url)
2. The heat generated will rise in proportion to the resistance.
The greater the internal resistance of the battery, the greater the amount of heat will be generated for any given value of current.

Because the resistance of a cell is effectively fixed, this is not a factor over which we have any control, except when deciding which cells to buy.

For batteries used at high loads, such as for powering the motors of model aircraft, the effects of internal heating are significant especially at high currents.

Conversely, for batteries which are used at relatively low loads such as in transmitters and for use as receiver batteries, the amount of internal heating is negligible and it may be disregarded.

Heat in Transmitter & Receiver batteries
A transmitter or receiver battery will not normally become warm in use, although some warming may be noticed when the battery is under charge.

Heat in Flight Packs
For hydride and nicad batteries used as flight packs, the tendency to become warm will be much more noticeable, especially if the battery is being used to supply a heavy discharge current, or being fast charged.

Left: A transmitters consume a relatively small current, typically around 250mA. The heat generated at this current is negligible, even if the battery has a relatively high resistance. Right: However, if a transmitter battery is fast charged, especially if charging is carried out in an enclosed space, the heat generated can become significant. For this reason, fast charging of transmitter batteries should always be carried out with the battery removed from the transmitter.
Chapter 4
Introduction to Nickel-based cells

There are two types of Nickel-based batteries in common modelling usage; the Nickel Metal Hydride battery (NiMH) and to a lesser extent, the Nickel Cadmium (NiCd) type. Cell capacities typically range from 50mAh to 4,000mAh. The two chemistries are similar and they have a lot in common. For convenience we will deal with them together; where significant differences exist, these will be discussed.

Nickel-based batteries are most commonly used for supplying transmitter and receiver power. They are also commonly used as the drive battery for surface based models such as boats and cars. They are also used for some aircraft applications, although LiPo batteries are now the usual choice here. It should be appreciated that the sort of current demand that is placed on Nickel-based cells in high power electric modelling applications such as the drive battery for aircraft and high performance cars is almost always well outside of their manufacturer’s recommendations ~ put more simply, what we as modellers do with the cells would often be considered to be abuse by their manufacturers. Consequently, to ensure an acceptable degree of safety, cells must be handled very carefully.

The Nickel Metal Hydride cell – characteristics and applications:
Nickel Metal Hydride cells use thin plates of the metals Nickel and a metal hydride, rolled up with electrolyte between them. These cells are a nominal 1.2 volts. They are often colloquially known as ‘nimms’ or ‘hydrides’, and sometimes written NiMH for short. The most obvious advantage of hydrides is their higher capacity (typically 30 - 50%) compared to the same size nicad; their capacity for a given weight is higher.

However, hydrides are less durable and may have a higher internal resistance. This means that they are most suitable for lower current applications or where their weight advantage is especially useful. Their higher internal resistance means that hydrides are generally limited to maximum charge rates of 1C - this, of course, means that the minimum time in which a hydride battery can be charged is one hour. This higher internal resistance also means that permissible discharge currents are lower than for nicad cells. The larger hydride cells (e.g. 2,000mAh and above) will comfortably tolerate up to about 10C and the smaller ones generally a little less, perhaps 8C.

To fast charge hydrides, a charger with specific NiMh capability is needed, otherwise cells are liable to become overcharged. Hydrides have traditionally best been used where a long duration was a requirement coupled with a modest current drain, for example in the case of transmitter batteries. Experience so far indicates that the capacity of hydrides tends to drop off after considerable use to a much greater degree than with nicad types.

The Nickel Cadmium cell – characteristics and applications:
Nicad cells use thin plates of the metals nickel and cadmium, rolled up with electrolyte between them. They are also nominally 1.2V and are characterized by low internal resistance. Most types in modelling use are suitable for fast charging (generally up to about 2C depending on cell type) and fast discharging (up to about 20C, depending on cell). This low internal resistance makes nicads a good choice for high current applications. A good quality nicad battery could last for many years, particularly if used
carefully and at lower currents. They are both easy to charge and forgiving of overcharging and deep discharging, making them especially suitable for the beginner.

<table>
<thead>
<tr>
<th></th>
<th>NiCd</th>
<th>NiMh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal voltage per cell</td>
<td>1.2v</td>
<td>1.2V</td>
</tr>
<tr>
<td>Internal resistance</td>
<td>Low</td>
<td>Higher</td>
</tr>
<tr>
<td>Normal max discharge current</td>
<td>Up to 20C</td>
<td>Up to 10C</td>
</tr>
<tr>
<td>Charge current</td>
<td>Up to 2C</td>
<td>Up to 1C</td>
</tr>
<tr>
<td>Durability</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Capacity per unit weight</td>
<td>Moderate</td>
<td>Higher</td>
</tr>
</tbody>
</table>

‘C’ Limits
Please note that the C limits mentioned for nicads and hydrides are an indication of sensible maximum currents for normal use. It is impossible to give specific limits because these will depend entirely on the particular type of cell in question and its application. The most reliable guide to an appropriate current is the resulting cell temperature. At high currents, cooling of cells after use becomes important and cell life will be reduced.

If very high currents are required, it is far better to use a more suitable cell type such as Lithium Polymer rather than risking damaging a hydride battery.

**Behavior of cells under different loads**

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Cell Voltage Off-Load
The off-load voltage of both nicad and hydride cells is usually close to their nominal voltage; if we measure the voltage of a fully charged cell, off load, it might be as high as 1.30 Volts. If the cell has only very recently been charged, a slightly higher voltage might be observed.

Cell Voltage On-Load
Under a light load, the voltage of a cell will remain close to its nominal voltage until almost exhausted ~ the discharge curve is said to be ‘flat’. However, with a heavier load, we can expect the cell voltage to drop significantly. The heavier the load, the more this voltage drop will be ~ if a cell is placed under a particularly heavy load its voltage may fall to approximately 1 Volt per cell, due to internal resistance. Hydrides are of course likely to suffer a greater voltage drop on load, and where hydrides are used at higher currents an additional cell is sometimes used to compensate for this, for example an 8 cell NiMh battery might replace a 7 cell NiCd battery. This need for an additional cell does of course negate some of the hydride’s weight advantage.

The diagram above shows the discharge characteristics of a typical nickel-based cell. (exaggerated for clarity) The green (upper) line represents the battery voltage under a very light load. In this condition the battery voltage will be almost the same as the open-circuit or off load voltage, and the diagram reflects this; the green line is nearly flat. Notice that as the battery discharges under a light load its voltage drops very little over the course of the discharge cycle; its voltage is nearly the same when in a high state of charge as when in a low state of charge. This small range of voltage is arrowed in red and indicated by the small green letter ‘v’ on the left hand side of the diagram. From this we can see that measuring its ‘off load’ voltage of a battery is a rather inaccurate way to tell its state of charge.

The blue (lower) line shows the same cell under a heavier load. Notice that the slope of the line representing the battery voltage has become steeper, although it is still relatively flat. There is a greater range of voltage between the charged (high state of charge) and exhausted (low state of charge) conditions, shown by the larger blue letter ‘V’, making it easier to determine the state of charge of the cell by measuring its voltage. This is the reason that receiver battery checkers put the battery under load. A further reason for this is that a damaged cell that has developed a very high internal resistance might easily show the same voltage as a healthy cell, until it is placed on load. To determine the condition and state of charge of a nickel-based cell it is therefore essential to place it under load.

Voltage recovery
As soon as a load is removed from a cell it will immediately start to ‘recover’ back to the off load voltage determined by its state of charge. This is why an apparently exhausted battery, after a short rest is often able to give another short burst of power (see also the later section on ‘micro cells’)

Cell voltage during slow charging
The voltage of a cell during slow charging will rise slowly as the cell is recharged. The rate of increase will be very gradual, and the cell’s exact voltage will depend on the particular charge rate, the type and condition of the cell etc. A typical nicad or hydride battery might reach approximately 1.35V per cell during slow charging.
**Cell voltage during fast charging**

Both the cell voltage and the rate of voltage increase during fast charging will be higher than when slow charging. Again, the cell’s actual voltage will depend on the particular charge rate, the type and condition of the cell etc. A typical nicad cell might rise to perhaps 1.5V per cell during fast charging at the 1C rate. At higher charge rates, the cell voltage will rise even further; the higher the charge rate used, the greater the voltage will tend to be.

![Cell Voltage at full charge](image)

Cell voltage under charge is a somewhat artificial figure because what is really being measured is the charger voltage necessary to drive the charge current – the higher the current required, and the higher the internal resistance of the cell under charge, the greater the charger voltage will need to be.

When fast charging, the cell’s voltage will fall very slightly once it reaches a state of full charge. The diagram here illustrates the phenomenon. Notice how the fall in voltage shows up as a small ‘peak’ as the cells become fully charged.

This characteristic is exploited by the so called ‘delta peak’ chargers which work by detecting this voltage fall to automatically terminate charging.

The value of this voltage ‘peak’ is very small - about 10mV (1/100 or 0.01 V) per cell for nicad batteries. For hydrides the fall is even smaller, about 5mV per cell, which is why they require a more sensitive charger to be successfully fast charged.
There is some evidence that well-used cells, particularly hydrides, can give a less pronounced voltage peak as they reach a fully charged state compared to when new. For this reason, it is worth taking additional care when charging well used cells.

**Battery voltage at conclusion of charge**
Once charging has been stopped, battery voltage will fall towards the off load value appropriate to its state of charge. To illustrate this, consider a 7-cell pack (nominally 8.4 Volts) while being fast charged; it might typically show a voltage of 10.5 Volts or more. However, when the charge current is stopped, the battery voltage would begin to decay to a value closer to its nominal voltage.

**Internal cell pressure during charging**
When a cell is recharged, its internal pressure will progressively rise, particularly as the cell approaches a fully charged state. At low charge rates, this pressure will remain low. When fast charging, cell pressure will be considerably higher but will remain at a safe value if the cell is not overcharged. If, however, a cell was severely overcharged it would become hot, its pressure would rise dramatically and the cell might be in danger of exploding; this is the reason overcharging is dangerous at fast charge rates, apart from the risk of damaging the cell. To guard against this possibility, fast charge cells are fitted with a vent in the form of a plastic valve to allow electrolyte to be released if internal pressure becomes dangerously high. Such vents are of course normally sealed in the closed position.

**Vents**
A vented cell may be identified as such by the presence of a small hole in its positive end. Please be aware that vents do not always prevent explosions occurring in overcharge situations and they must not be relied upon to give explosion protection, particularly if the cells have been soldered during assembly due to the chance of solder heat damaging the valve. If the vent does operate electrolyte will be released and the cell will therefore have lost part of its capacity.

*Left:* The vent of this 2,400mAh Sub C size nicad cell was blocked by careless soldering. When the cell was overcharged, the vent was unable to operate. This meant that the internal cell pressure kept rising until it was high enough to cause the end cap of the cell to separate. *Right:* Here’s another reason why the safety precautions section of this guide is worth reading! This pack exploded during overcharging. Presumably the vent did not function as it was designed to.
Chapter 5
Safety Precautions

Charging of nickel–based batteries is a low risk process, provided it is carried out properly. However, if abused, batteries can cause serious personal injury, so the subject of safety needs more than a cursory glance. Please give this chapter your full attention - the precautions may seem dull but ignoring them could turn out to be a lot more exciting than you may wish! It's also worth mentioning that the subject of safety cannot be contained in isolation, meaning that safety related information will be found throughout this guide.

Risks are low – but not zero
The risk of fire or explosions from NiCd and NiMh batteries is small, but is always present if they are mishandled. The main causes of such accidents are short circuits and overcharging:

Short circuits
Short circuits occur when the positive (e.g. red wire) and negative (black wire) parts of a battery become directly connected to each other. In this circumstance, a very high current can flow, (a shorted nicad ‘Sub-C’ cell can easily generate much more than 100 Amps) quickly causing wires to become extremely hot, easily hot enough to melt electrical insulation and even the wire itself. Short circuits represent a genuine fire risk and may also result in the battery suffering permanent internal damage.

Overcharging
Overcharging of batteries is unlikely if an appropriate charger is used correctly. Once a battery pack is fully charged, do not be tempted to try to force more charge into it; the excess energy will simply be dissipated as heat and may cause damage.
It is quite normal for hydride and nicad cells to become warm to the touch when fast charging. If a battery feels hot it has probably been overcharged and could explode. Disconnect it at once and move away from it until it has had time to cool. If possible, place a cooling fan near the battery.

Do not fast-charge a warm battery (e.g. just after it has been used in a high power application) - allow it to cool before fast charging. A separate battery cooling fan may be used for this purpose.

**Charge leads**

Some chargers require a separate, detachable charger-to-battery lead. These often have unprotected 4mm plugs at the charger end. The plugs will become live if the lead is connected to the battery alone and could easily touch and cause short circuiting of the battery.

A simple precaution against this risk is to leave the charger-to-battery lead permanently connected to the charger. Alternatively, always connect the charger-to-battery lead to the charger before connecting a battery, and always disconnect the battery before disconnecting the charger-to-battery lead from the charger itself.

*Left: The danger of connecting the charge leads to the battery first is well illustrated here. Right: The solution to this problem is simple – just make sure the charge leads are connected to the charger before connecting the battery.*

The resistance of the entire charging lead (i.e. connectors and wire) will be assessed by a microprocessor controlled charger as part of cell resistance; high resistance charge leads may cause a reduced charge current to be selected by the charger.

**Other safety precautions**

Ensure that your charger and batteries have sufficient ventilation. Do not charge batteries in an enclosed space, for example in a hot car with the windows closed. Be very careful if fast charging a battery in a model because the inevitable heat generated within a battery may not be able to dissipate quickly enough.
Charging is always safest in dry, cool conditions, with both charger and battery out of direct sunlight. Do not cover up a charger’s ventilation holes and don’t leave peak-detect chargers completely unattended while charging or discharging ~ things do occasionally go wrong!

**Fast charging receiver batteries in a model**

It is a good idea to protect a model’s receiver battery by wrapping it in shock absorbing foam. This will offer a measure of protection against vibration, and will help to protect the battery in the event of a crash.

However, it is wise to be very cautious about fast charging receiver batteries which are wrapped in foam – since the foam is an excellent insulator, any heat generated will not be able to escape easily. If the battery is overcharged, the insulated battery may well become excessively hot. The photos below illustrate what can happen in such a situation:

![Left: This receiver battery was fast charged while wrapped in protective foam inside a model. The battery became overcharged, with these ugly consequences. It is a sound policy to fast charge receiver batteries outside of the model, where the charge process can be better monitored. Right: This is another view of the receiver battery which suffered damage during routine charging.](image-url)
Methods of charging
There are two common methods of recharging nicad and hydride cells; slow charging, typically requiring 14 hours, and fast charging, which can, depending on the cells, be accomplished in less than one hour. Once a cell is fully charged, if the charging current continues to flow, the excess energy is dissipated as heat. Some useful graphs concerning charging appear later in this publication.

Slow charging
Slow chargers, such as those invariably supplied with RC equipment, usually charge at the C/10 rate. Theoretically, charging at the C/10 rate should take only 10 hours for a full charge. However, an ‘overcharge’ of up to 40% is necessary to ensure that each cell within a battery reaches a full state of charge because: (a) charging is not 100% efficient; (b) the actual charge current may in fact be significantly less than that specified on the charger; and (c) it is impossible to know accurately when cells are fully charged. This means that, if it is required to ensure that cells are fully charged before use (always wise), some overcharging is unavoidable in practice. Limited overcharging at slow charge rates is useful to ensure that all cells within the pack are fully charged and need not be a source of concern. However, unnecessary overcharging at the slow rate should be avoided.

Battery temperature rise during slow charging
Cells will typically show a very slight temperature rise during slow charging. This rise is due to the internal resistance of the cells. Any temperature rise will be difficult to detect by touch except perhaps during the overcharge phase. It is considered safe to leave batteries unattended while slow charging because the amount of heat generated is low and will not cause cells to become excessively warm.

Left and Right: The technology contained within modern microprocessor chargers like these examples is astonishing. An important part of the purchase decision process is to make sure that the selected charger is easy to use. This is likely to be of particular importance the more mature modeller.
Fast charging
It is vitally important to ensure that an appropriate charge rate is used if fast charging. Unlike slow charging, any significant overcharging at fast charge rates will probably cause damage to cells. A means of determining when cells are charged is thus required.

The ‘delta peak’ method is used by fast chargers, explained in the previous chapter. Such peak detect chargers are usually very reliable, but it is still possible for a charger to malfunction and fail to detect the end of charge point. If charge continues to be passed in to a fully charged battery the excess energy is converted into heat. At fast charge rates this excess energy can represent a lot of heat and a battery can become extremely hot. For this reason, it is not recommended to leave batteries completely unattended when fast charging.

Temperature rise during fast charging
While fast charging, most of the electrical energy being passed through the cells is used for recharging. The cells will show a small but noticeable temperature rise, particularly as they approach the fully charged state. This temperature rise may be quite easy to detect by hand. However, once the cells are fully charged, if the charging current continues to be passed through them, all the excess energy will be dissipated as heat. Overcharging is harmful and if prolonged, cells may become dangerously hot and even explode.

An overview of fast charge rates
Charge rates are normally referred to as a multiple of battery capacity. To recap, the ‘1C’ rate (one times the capacity) for a 500mAh capacity battery would be 500mA, which could also be written as 0.5A (500mA = 0.5A). Theoretically, this would mean that the battery would be fully charged from flat in 1 hour. Similarly, the 2C rate would be 1A and 30 minutes would be required for a full charge.

Remember that in modeling applications, when fast charging, the charge and discharge currents typically used are well outside battery manufacturers’ recommendations. This makes it especially important to ensure that the charge rate used is suitable for your battery, both for your safety and that of your batteries and models. It is probably wise to limit charge rates to a maximum of 1C unless cells are vented.

Fast charging Nickel Cadmium (NiCd) cells
Virtually all nicad batteries are capable of accepting a 1C charge rate without damage. Some sub-C sized cells will accept 2C and a few perhaps 3C. Generally speaking, AA size cells are best kept to 1C as a maximum. When fast charging, especially at rates above 1C, it is important to ensure that great care is taken to avoid damage to the cells.

Fast charging Nickel Metal Hydride (NiMh) cells
Due to their higher internal resistance and different cell chemistry, hydrides require more careful charging than nicad types. It is recommended to charge hydrides at a maximum of 1C. This is the reason that some computer-controlled chargers restrict the maximum allowable charge rate to 1C when NiMh is selected as the battery type. Note that hydrides may show a stronger tendency to rise in temperature towards the end of charge than nicads.

Waiting time
In general, for charge rates above about 1C, the more rapid the charge rate, the lower the lifespan of the battery will be. It is therefore a good idea to charge batteries at the
lowest rate that is convenient for your needs. For batteries used as the power source for a model’s motor, the purchase of a second battery may be helpful to reduce waiting time due to charging. This means that one battery may be charged while another is used. For electric gliders with long flight times a second battery can almost eliminate waiting time. For higher power models such as power boats, a system of two chargers and three battery packs is an excellent (though expensive) way to save time; while one battery is being used, two more are being charged.

Checking the amount of charge given to a battery
Occasionally, it is possible for a ‘false peak’ to be detected by a charger, usually early on in the charge process, causing charging to be prematurely terminated. The only reliable way to ensure that this has not occurred is to check at the end of charge that the charge quantity supplied to the cells corresponds to the expected amount. For chargers that do not display the charge quantity, occasional monitoring of the charging process, especially for the first few minutes of charge, is the only precaution available. Premature charge termination is most likely to occur when charging low cell-count packs or deeply discharged packs.

Charger current for high cell-count packs
All microprocessor controlled fast chargers operating from 12 Volt lead acid batteries incorporate internal voltage increasing circuitry. This means that when charging batteries of more than about 7 cells, a current greater than the charge current will be taken from the lead acid battery. For example, when charging a 14 cell pack at 2.4A, approximately 5A will be taken from the lead acid supply battery.

Top-up charges
It may be tempting to try and ‘squeeze’ a bit more charge into cells that are already charged. Such ‘re-peaking’ is unnecessary; cells that are full cannot become any fuller! It is also risky because the charger may not be able to detect a voltage peak a second time if all cells in a pack have already passed their voltage peak, so overcharging is a distinct possibility. If you still wish to top cells up I would suggest that a good rule of thumb is not to do so unless at least 20 minutes has elapsed since charging, by which time at least a small amount of charge will have naturally been lost. Also, it is a good idea to use a modest charge rate for ‘topping up’ and to constantly monitor the charging process with particular attention to cell temperature.

Charging cells for use in high power applications
Batteries used in high power applications may well only deliver their maximum performance if charged at a comparatively rapid rate shortly before they are required for use. This particularly applies to batteries subject to discharge rates around 10C and above (i.e. cells become flat in 6 minutes or less). In such models, it is sometimes noticed that the cells deliver their best performance after a few flights.

Charging new batteries
It is important that new batteries are charged at the C/10 rate for at least 14 hours before first use. This is said to ‘form’ the cells. This also applies to batteries brought out of storage. It is also worth considering cycling a new battery to confirm its condition and capacity prior to first use, particularly if it is to be used in a safety-critical application (e.g. transmitter or receiver battery). For high-power applications (e.g. motor battery) it is probably a good idea to cycle a battery at a modest rate for the first one or two cycles. Further information on cycling may be found in the chapter on testing.
Finding an appropriate slow charge time.
A wide variety of slow chargers and battery capacities are available. If the charger is not exactly matched to the C/10 rate for the battery in question, you may find the graphs in chapter 10 useful - they will enable you to easily find the required charge times for almost any combination of cell and charger.

Reflex or 'Burp' charging
This charging technique involves repeatedly interrupting the charging process with short discharge pulses. It is claimed to break any memory effect that a battery may be harbouring, however, at the time of writing, there are no chargers in the modelling field featuring this facility, and evidence for real advantage is lacking.

Charging at low temperatures
The internal resistance will be higher if the cell is cold, so in cold weather it may be worth considering the use of a slightly reduced charge rate for the first fast charge.

Alternative method to calculate charge times:
If battery capacity in mAh = BC
Charger current in mA = CC:
Charge time in hours = \( \frac{BC}{CC} \times 1.4 \)

For example, suppose we have a 2,400mAh battery and we wish to use a 70mA charger on it. The theoretical charge time would be 2400 / 70 hrs = 35 hrs. We would add up to another 40% to ensure a full charge so the time required would be a maximum of 2400 / 70 x 1.4 = 48 hrs.

A History of Nicad Fast Charging.
When Nicad batteries first appeared on the modelling market, it was common practice to see a simple ‘resistive’ charger being used. These typically relied on the modeller connecting the model’s battery directly to a 12V source battery, and manually timing the length of charge. If fewer than 8 cells were being charged a resistor would be used in series with the Nicad to limit the current. It was a hit and miss process with many variables, and dangerous to get wrong because the battery could easily become overcharged and get very hot. I had a pack actually explode around 1980 using this charge method; fortunately I was not injured.

The next step in battery charger evolution was the introduction of a clockwork timer, added to the simple resistive charger. This was an improvement because it meant that forgetting about the battery was less of a problem, but these chargers still relied on the user setting the correct length of charge.

The introduction of the fully automatic ‘peak detect’ charger has provided an almost foolproof solution to the problem of fast charging batteries safely.
Discharge rate and battery capacity
The rate at which a battery is discharged will affect the available capacity of a battery - the faster a battery is discharged, the lower recovered capacity will be because at high currents more energy is lost in the form of heat within the cells, so less energy is available for use elsewhere. Battery capacity is normally quoted by manufacturers as the capacity delivered at a 5-hour discharge rate i.e. the rate which will cause the battery to become exhausted in 5 hours. For example, a fully charged 500mAh battery discharged at 100mA would theoretically become exhausted in 5 hours.

In modelling applications, even receiver batteries are usually discharged at considerably higher rates than this, which means that in practice, a lower usable capacity will actually be available than the printing on the battery sleeve might suggest. Regularly testing the capacity of a battery helps to ensure that it is safe to use in a model.

Reverse charging
The cells within a battery, although very similar, will never be identical; they will differ slightly from one another in terms of capacity and voltage. A consequence of these small capacity differences is that as a battery is discharged, one (or more) of the cells in a battery will become exhausted before the rest. If discharging is continued, the voltage of this ‘weakest’ cell may fall so far that it actually becomes zero. If discharging of the battery were continued still further this particular cell would then be forced below zero volts, into a reverse charged condition.

To guard against this possibility, it is usual to terminate discharging when a battery falls to approximately 0.9V per cell, for example at around 6.3V for a 7-cell battery. This is considered a ‘safe low voltage’, and is intended to prevent the weakest individual cells in a pack from becoming reverse-charged. The greater the number of cells in a pack, the higher the chance of an individual cell becoming reverse charged. Speed controllers include an integral ‘power cut-off’ (PCO) which will cut power to the motor when battery voltage falls to a particular value. The primary purpose of this is to protect the supply of power to the receiver, but happily an additional benefit of the PCO function is that the chance of cells becoming reverse charged is reduced.

Cells are not designed to be reverse charged and every effort should be made to avoid this condition developing. Any type of cells may suffer damage by reverse charging. However, hydrides are far less tolerant than nicads in this respect, and even one episode of reverse charging may damage them permanently. Reverse charging, even at low currents, is detrimental, and cells may become badly damaged if this is done repeatedly. Reverse charging at high currents is dangerous because if continued for more than a short time cells could explode.

If reverse charging has occurred, or is suspected, with either type of cell simply recharge, preferably at C/10 and hope for the best! It may initially be necessary to charge at a much higher rate for a very short period to get cells to accept charge after a reverse charging episode.
**Discharging and the effect of temperature**

Chemical reactions tend to be accelerated at raised temperatures. Batteries, being essentially chemical devices, will also be affected by temperature. Warm batteries will tend to perform much better than cold ones (especially hydride types) because, generally, they will exhibit a slightly lower internal resistance and a slightly higher voltage.

The effects of temperature may be quite noticeable when operating electric models; high performance models in particular are often found to perform significantly better after one or two flights. This is not because of a change in the motor (in fact, all else being equal, warm electric motors are slightly less powerful than cold ones) but because of changes within the battery. The reasons for this are two-fold; firstly the cells will have been warmed by being used, and secondly they will have enjoyed the benefits of having been cycled (cycling is fully explained in a later chapter).

Although for maximum performance warm cells are preferable to cold ones, it does not follow that hot cells are even better - it is important not to allow cells to become hot for reasons of safety (risk of venting and/or explosion) and battery longevity.

**Battery capacity and the effects of temperature**

Battery capacity will also be affected by temperature; cold batteries will tend to suffer a reduction in their available capacity. One consequence of this is that during winter, a cold receiver battery could become exhausted well before expected. An interim top-up charge is a wise precaution in such cold conditions. It is a good idea to wrap receiver batteries in foam when installing them in a model. The foam will help the battery retain any warmth gained during charging, and may result in slightly more capacity being available in cold weather compared to an unwrapped battery. The foam will also help to isolate the battery from vibration and give it some measure of protection in a crash. Be careful not to allow a wrapped battery to overheat if charging it within a model.

**Limitation of ready-made packs**

A practical continuous current limit for mass-produced ready-made Sub C battery packs is usually around 30-35A, with a correspondingly lower limit for smaller cells. The limit is due to the resistance of the relatively thin metal tags connecting the individual cells; an even lower limit will apply if these tags are unduly thin or if very few weld spots have been used to attach them. The effect of tags (or wire) of too small a cross section will be to increase the resistance of the battery pack. Such tags may become hot under load, wasting energy and reducing motor power.

The simplest solution to this problem is to use a thicker, lower resistance connection between cells, for example substantial wire or copper strip. Another solution is to assemble packs by soldering each individual cell directly to the next one, in an end-to-end configuration. This method gives the lowest possible connection resistance since interconnecting tags are eliminated. Although it is common modelling practice, it must be mentioned that soldering directly to cells is not recommended by any cell manufacturer for safety reasons. Nevertheless, some specialist battery suppliers will supply cells joined in this way. For home assembling of batteries in this way, the correct tools and experienced help should be sought.
Chapter 8
Inside cells

We have already seen that the internal resistance of a cell will cause a voltage drop, and that the greater the current the more the voltage drop will be. Let us now consider the internal construction of a cell. In diagram (a) below we see two of the battery’s rolled up internal plates. Diagram (b) shows the same plates, now unrolled and looking nearly flat, something like those of the familiar car battery.

‘Micro Cells’
For convenience, we can consider the plates to be divided into 3 separate zones. Zone A is the region closest to the cell terminals, and zone C the region furthest away, deep inside the cell. The materials from which the cell plates are made have electrical resistance, so the electrical path to reach zone A will be of lower resistance, and the path to reach zone C will have the higher resistance. Diagram (c) represents this where each zone has become a separate ‘micro-cell’ in parallel with the others.

Note that there is an electrical path from one plate to the other as well as a path up and down each plate. Rp represents the resistance between each of the plates, and Rz the resistance between zones. Micro-cell ‘A’ has the lowest resistance path from the cell terminals (Rz + Rp) so it will only suffer a small voltage drop. Micro-cell ‘B’ has a greater resistance (Rz + Rz + Rp) and will therefore suffer a greater voltage drop. Micro-cell ‘C’ will suffer the greatest voltage drop because it has the highest resistance path from the terminals (Rz + Rz + Rz + Rp).

Under small currents, these voltage drops will be virtually negligible, and the micro-cells will allow themselves to be discharged almost equally. However, under a heavy discharge current, micro-cell A, with the smallest voltage drop, will tend to give up its charge more easily, whereas micro-cell C, deep inside the cell and with the largest drop will tend to give its charge up less easily. The cell material nearest to the terminals is therefore the most readily ‘exercised’ i.e. more easily gives up or accepts an electrical...
charge. Conversely, the material in the deepest parts of the cell is the most reluctant to be exercised.

The division of the cell into 3 zones is of course a convenient approximation to allow a simple explanation of the principle. In actual fact electrical resistance will gradually increase as we consider the plate regions further and further away from the terminals.

Some effects of ‘micro-cells’
With an understanding of cells in terms of zones/micro-cells, it is now easy to explain in a practical way some cell characteristics that are easily observed. We would expect a cell to have a lower resistance when fully charged and a higher resistance as the end of discharge approaches, when micro-cell C is emptied. This is indeed observed in practice, and is largely responsible for the voltage slope seen on discharge graphs.

If a discharged cell is fast charged for a short period of time it may, when checked with a voltmeter, appear (incorrectly) to be in a high state of charge. The reason for the illusion is that only the material nearest the terminals has been significantly charged, whereas the material deeper inside the cell may have received very little charge. The voltmeter is simply reading the state of charge of the most highly charged material. If placed on load, the cell’s voltage will fall quickly as the charged portion gives up its charge, or if left standing, voltage will be seen to fall gradually as the charge gradually dissipates throughout the cell. These effects may be readily observed on the battery indicator of a discharged mobile telephone after a short charge.

Microprocessor controlled chargers will reduce the charge current as the end of charge approaches - this reduces the voltage drop (which is proportional to current) across the battery’s more remote zones, to ensure they reach a state of full charge.

Obsolete battery practices

Some years ago, when nicads were the only available choice for high power applications, competition modellers used specialist techniques to try and gain the very best from these cells. It may be interesting to have a little detail about these now obsolete practices:

**Matching cells** – A battery that is made from ‘matched’ cells is one in which the cells have been tested, and chosen for their close similarity to each other. Matched cells will give models a slightly better performance, but battery voltage will tend to fall rapidly at the end of discharge since cells will all reach a fully discharged condition at almost the same moment. Matched packs tended to have a longer life compared to unmatched packs since it was more likely that no individual cell will be significantly weaker than any of the others.

**Zapping (also known as ‘pushing’)** – It was discovered that discharging a powerful capacitor through a nicad cell resulted in the cell enjoying a slightly lower internal resistance afterwards. This gave a slight performance advantage at high discharge currents. Such cells were said to have been ‘zapped’ or ‘pushed’. The advantages gained were of greatest significance to the competition modeller.
Chapter 9  
**Memory Effect or Voltage Depression**

Few subjects in modelling have generated as much controversy as the so called 'memory effect' in nicad batteries. Almost everyone seems to have heard of it but there seems to be no universal agreement as to its cause, or even that it exists at all! In any case, it need not be a source of concern to modellers; it is easy to prevent and simple to cure if suspected.

Memory effect is said to have first been discovered in nicad batteries that were repeatedly only partially discharged to exactly the same point before recharging. After many such cycles, the cells apparently 'remembered' how much capacity was required of them on previous discharges by appearing to refuse to deliver a greater capacity. NiMh cells are thought to be less prone to suffer from 'memory effect'.

Memory effect is in fact more correctly called 'voltage depression' for reasons that will become clear shortly. At present the most satisfactory explanation for it probably concerns the crystalline structure within the cell: inside a cell, electrolyte crystals are thought to be present on the cell's internal plates or electrodes. The highest cell capacity is thought to occur when the crystals are many in number and small in size. In this condition, the total surface area of the crystals is large and the cell's capacity will be at a maximum.

However, if the cell is kept partly or fully charged, over time these crystals tend to grow by becoming fewer in number but larger in size. Larger crystals are bad news because they have a lower total surface area and cause the affected zone’s internal resistance to rise. This will cause the on-load voltage of the affected zone to be reduced – hence the term ‘voltage depression’. In severe cases voltage can be greatly reduced under load. The result of a reduced voltage under normal discharge currents is that the battery can appear to be prematurely exhausted; it is this effect that gives rise to an apparent reduction in capacity. It is believed that the formation of large crystals can be caused in several different ways:

- Repeated recharging of cells from a part-discharged state
- Prolonged overcharging at the slow rate
- Storing cells in a charged condition
- Recharging well before necessary in terms of time

Notice that each of the 4 cases above is equivalent to one or more of the micro-cells, or zones, being kept in a charged condition for extended periods of time. For example, repeatedly recharging cells from a part-discharged state will mean that the deepest part of the cell is being kept permanently charged.

**Preventing Voltage Depression or ‘Memory Effect’**

If a battery has a lower than nominal capacity, it may be suffering from voltage depression. Voltage depression or 'memory effect' is easy to prevent. Simply take care to minimise the amount of time cells are stored in conditions that allow the larger crystals to form:
If convenient, leave batteries in a discharged condition between uses (This will also help prevent cells from becoming unbalanced; see later)

Ensure batteries are fully discharged occasionally so that all the material in a pack is exercised. Some modelers always fully discharge a battery after use, before recharging; this may be beneficial provided no reverse charging occurs.

Use your cells ~ cycling encourages small crystals.

**Treating Voltage Depression or ‘Memory Effect’**

If voltage depression is suspected, it is easy to erase; large crystals, once formed, can be broken down into smaller ones by the act of cycling the cells. Cycling at a relatively low discharge current may be particularly beneficial because it should enable the deeper regions of the cell to become more fully discharged. An ‘intelligent’ charger will be able to measure battery capacity and it is a simple matter to compare ‘before’ and ‘after’ capacities. Several cycles may be needed for best result.

**Storing Hydride and Nicad Batteries**

Nicad batteries are best stored in a discharged condition to help prevent voltage depression developing (see ‘memory effect’). There is some evidence to suggest that it may be wise to store hydride cells in a low, but not fully discharged state; for these cells, discharge the pack and then replace about a quarter of the capacity before storing the battery.

All batteries should be stored in a dry environment to reduce the chance of black wire syndrome developing (See ‘Black Wire Syndrome’). Also, remove transmitter (Tx) batteries from transmitters, and disconnect receiver (Rx) batteries from models in storage. This ensures that if black wire syndrome does occur, it cannot spread to the rest of the RC system. It may be beneficial to cycle a stored nicad battery every, say 3 to 6 months, and possibly more frequently for hydrides.

Cool conditions are preferable for the long-term storage of batteries.

**Bringing batteries out of storage**

Batteries being brought out of storage should be treated as for new batteries. The procedures for these are detailed elsewhere. Note that if a nicad or hydride cell is not used for a period of time, it will show a higher resistance than usual to being charged or discharged.
Chapter 10
Transmitter and Receiver Batteries

All of the information in this guide applies to transmitter and receiver batteries, but nevertheless it is worth covering a few areas which are specific to this particular type of application.

One of the disadvantages of hydride batteries, and to a lesser extent the nicad variety as well, is that as soon as they are charged, they begin to self-discharge. This of course rather unhelpful, meaning that a transmitter which was charged up on say Sunday night has rather less than a full charge in it by the following weekend. Consequently the only way to be confident that a battery has close to a full charge at the beginning of a flying session is to charge it up shortly before use.

Low self-discharge cells
A recent innovation is the low self discharge hydride battery, one example of which is the ‘Eneloop’ brand from Sanyo. These batteries are very similar to ordinary hydrides, but with the useful advantage of enjoying a much lower rate of self discharge.

Left: This Eneloop receiver pack with its low self-discharge rate may be expected to hold its charge for much longer than a conventional hydride receiver pack. Right: Low self discharge hydride cells such as these from Sanyo branded ‘Eneloop’ are a suitable choice for a transmitter battery.

Fast charging of transmitter and receiver batteries
Few modellers seem willing to consider fast charging transmitter and receiver batteries. This is understandable since the charger supplied with RC equipment is invariably a slow charger, so perhaps fast charging is perceived as ‘abuse’ of these cells. However, batteries in poor condition will frequently appear to charge normally using a slow charger; if they are also never cycled their true condition can remain hidden until a model is lost due to a flat (faulty) battery. An important advantage of fast charging is that a faulty cell is more likely to show up, thus giving advance warning of a battery problem. Fast charging of RC batteries also gives more flexibility because pre-planning a flying session becomes nearly unnecessary. Provided fast charging is carried out with care,
the cells are suitable, and an appropriate current is used, there is no reason not to fast charge transmitter and receiver batteries. Take care not to use an excessive charge current—probably 1C should not be exceeded for such cells. It is of course absolutely essential that premature charge termination does not occur with any safety-critical batteries.

**Remove your transmitter battery when fast charging it**
Transmitter batteries are best removed for fast charging or discharging because: (a) many transmitters are fitted with ‘blocking’ diodes which prevent some peak detect chargers from operating; (b) internal wiring, hidden from view, may not be suitable for fast charging, and (c) to prevent possible transmitter and battery damage through overheating, due to the battery being in a confined space.

**Fast charging receiver batteries**
It is safest to separate a receiver battery from its switch harness before fast charging. If this is not possible, the charge current will have to pass through the switch harness; take care not to overload it. Most harnesses should be able to accept a continuous 500mA without damage. Also, be aware that fast charged receiver batteries may not be able to dissipate heat quickly if they are tightly encapsulated within a model.

**Transmitter battery state of charge**
Transmitters invariably include a meter showing the battery state of charge, and some also feature an audible warning of a low charge state. Whilst this is a useful feature, this function should not be relied upon for a warning while a model is flying – audible warnings are not always noticed by the pilot when close attention is given to flying a model, and in any case an audible warning may be obscured by other noises in the vicinity.

**How many flights is it safe to make?**
After an operating session the capacity remaining in a receiver battery can be measured by discharging it at a similar rate to that experienced by the battery in the model, using a suitable charger/discharger. A suitable discharge rate for testing might be 500 mA.

The maximum safe operating time of the model can therefore be calculated. For example, suppose a model has a receiver battery fitted with a nominal capacity of 650 mAh. Previous testing shows this battery actually delivers around 600 mAh. You fully charge the battery, and enjoy three flights with the model. You return home, and discharge the cells. Suppose this revealed that the battery was able to deliver a further 330 mAh of capacity before being exhausted—we can now work out the amount of charge used per flight:

\[
\text{Total amount of charge used} = \text{actual capacity} - \text{remaining capacity}
\]

\[
\text{Total amount of charge used} = 600 - 330 = 270\text{mAh}
\]

If 270mAh used over 3 flights; amount used per flight is 270/3 = 90mAh

It is sensible to plan on using not more than 2/3 of the battery’s capacity, so in this case we can plan on using 2/3 x 600mAH, which is 400mA. The model uses 90mA per flight, so 400/90 = 4.4 flights. So now we know that 4 flights is the safe maximum for this model, if starting with a fully charged battery.
Battery quality
It is worth considering the quality of the battery in your model - the most popular makes are not necessarily of the best quality. Also, it’s worth checking the actual capacity of a battery before relying on it in a model. At least one company labels batteries with the average expected capacity on the sleeve, so if you are unlucky, your battery could have a significantly lower capacity than expected.

Finally, it is probably worth paying a premium for top quality batteries; since the chances are that they will be less likely to let you down, and will have a longer service life.

Choosing a receiver power source.
There are many options for supplying the receiver and servos with power. These include a 4 or 5 cell hydride battery or a 2-cell LiPo battery and UBEC.

Left: For sport models with up to say 4 or 5 standard servos, a good quality hydride or nicad battery known to be in good condition and monitored with either an on-board battery indicator or an external tester constitutes a reliable source of energy for sport models. Right: For maximum reliability, a two or three cell LiPo battery plus a good quality UBEC may be a better solution for large, fast and/or expensive models.

Battery backers
For particularly valuable or large models a ‘battery backer’ may be considered. This is a small electronic device that supplies the receiver and servos from two, independent receiver batteries. The advantage with this system is that if one of the batteries should fail, the other will be able to independently supply power to the RC equipment. Battery backers invariably require the use of 5-cell receiver batteries.
Microprocessor-controlled charger/dischargers can make a valuable contribution to model safety as they allow us to determine the actual capacity of safety-critical batteries such as receiver batteries.

It is important to be confident that a receiver battery will not unexpectedly become exhausted during use; should this happen, your model will of course become uncontrollable. It is also useful to know the capacity of other batteries, such as flight batteries in model aircraft. The most important battery performance factors are

(1) The capacity of the battery and
(2) Its state of charge
(3) Its self discharge rate
(4) Its external condition
(5) Its internal condition

At the flying field we are principally interested in the state of charge of the battery, while and in a workshop testing situation the remaining factors are also of interest.

Checking batteries at the flying site
At the flying site, the most important thing to know about a battery is its state of charge. For RC models, the most safety-critical battery packs are those of the transmitter and receiver, which are usually hydride or nicad types.

Left and right: Modern microprocessor chargers are extremely useful for testing batteries. Almost all such chargers will allow batteries to be discharged and charged multiple times for test purposes.

Receiver battery state of charge
It is wise to check the state of charge of a receiver battery before every flight. An on-board battery monitor is a useful aid in this respect. While checking its display, it is
important to ensure that the model’s controls are operated to impose a representative load on the battery. Such monitors use very little power and are an excellent idea, providing enhanced safety at a modest cost and for a low weight penalty.

An alternative to an on-board monitor is a separate hand-held tester. If you use this kind of tester be sure that it tests the battery on load. The load should be the same or greater than the load that the battery will experience in actual use. A load of 250 mA is generally sufficient for this purpose. Note that testing of batteries in an off-load condition serves little purpose because it will not accurately reveal a battery’s state of charge. Also, if testing batteries after a short fast charge, please be aware that the cell’s actual state of charge may be a lot lower than that indicated by a correctly-used tester. (see the section on ‘micro cells’ for a detailed explanation)

Home testing of batteries
To test a battery for capacity and self-discharge rate, a microprocessor-controlled charger/discharger (cycler) or similar device able to record battery capacity will be required, along with a careful system of recording results. Appendix 2 contains a battery testing form which can be used either as shown, or altered to form the basis of your own testing system. You may like to repeat tests to check for consistency. In addition to checking the electrical performance of batteries, a physical examination of the pack is also a good idea. Check for any loose wires, dirty connectors, abraded insulation etc. Always carefully inspect a battery pack that has been involved in a crash, particularly if it is a receiver battery. Remember that a model’s RC equipment depends on the integrity of the battery for its power supply.

Left: Charge leads are available for almost any battery, making it easy to use an inexpensive microprocessor controlled charger/discharger/cycler to assess the performance of a battery. Right: Even older chargers such as the high selling Chamaleon isl 6-330d are useful assets in the workshop. An excellent e-book guide to this particular charger is available at www.gibbsguides.com which makes this charger very easy to use.

Choosing a suitable discharge rate for testing
When testing batteries for capacity, it is a good idea, where possible, to use a current at least as much as the current the battery will actually deliver in the application in question;
Finding the capacity of a battery
Recharge the battery fully (slow or fast charge method). If cells were fast charged, ensure they are all brought to a state of full charge by slow charging (C/10 rate) for a further 3-4 hours. As soon as this period is up, carry out one discharge cycle and record the result. The result of this test will reveal the maximum capacity of your battery, which may then be compared with its nominal capacity.

Self discharge rate (also known as charge retention)
Primary cells, i.e. ‘dry’ batteries, particularly alkaline types, tend to hold their charge for a long time if not used; their self discharge rate is low. By comparison, rechargeable (secondary) cells tend to be much worse at retaining a charge ~ such cells will begin to lose their charge as soon as charging has stopped. An awareness of this is important to avoid operating a model with a battery that is believed to be fully charged, but is in fact only partly-charged. This is most important with receiver and transmitter batteries.

The self-discharge rate of healthy batteries encountered in modelling applications are, very approximately, up to, say 15% per week for nicads and perhaps up to 20% per week for hydrides. Depending on the application in question, cells with a worse performance than this are not necessarily unfit for service.

The actual self-discharge rate will vary depending on the type and condition of the cell, and the storage temperature. Fast charge ‘high rate’ cells (e.g. motor batteries) have a slightly different internal construction and may tend to self-discharge more quickly than low-rate cells (e.g. transmitter battery) The rate of self-discharge is lowest when batteries are kept cool. A faulty battery could self discharge very quickly. An excessively high rate of self-discharge would be a good reason to retire a battery from a safety-critical application, even if its capacity was satisfactory. For a nicad, ‘excessive’ could mean above about 20% per week, or for a hydride battery above about 30% per week, depending on the application. The only way to be sure of the self discharge characteristics of a particular battery is to test it.

Finding the self-discharge rate of a battery
To do this, first determine and record the actual capacity of the battery, as above. Next, fully recharge it. If fast charging was used for this, you may wish to additionally slow charge the cells for a further period of 1-2 hours to ensure they are all brought to the same state of charge. Record the date and put the battery aside, ideally for a whole week. After this time, discharge the battery, record the capacity recovered and compare with the capacity recovered in the previous test. A simple way to assess whether or not the self-discharge rate is acceptable is to multiply the actual capacity of the battery by 0.7 for hydrides or 0.8 for nicads. The resulting figure is the ‘not less than’ figure for comparison after 1 week. If the capacity after 1 week is not less than this figure, the battery has an acceptable self-discharge rate.
Example: A receiver nicad battery has an actual capacity of 630mAh. It is recharged and set aside. The ‘not less than’ figure would be $630 \times 0.8 = 504$mAh. After 1 week the battery is discharged and found to have delivered 523mAh. This is more than the ‘not less than’ figure of 504mAh, so the battery has an acceptable self-discharge rate.

If you wish to use a more mathematical approach to calculating the self discharge rate, the following formula may be of interest. This is particularly useful if the battery has been set aside for a different period than a whole week.

If $AC = \text{actual capacity in mAh}$, $RC = \text{recovered capacity in mAh}$ & $D = \text{no of days set aside}$:

$$\text{Self discharge rate} = \frac{(AC—RC)}{AC} \times \frac{7}{D} \times 100$$

Interpreting test results
A battery delivering its rated capacity and with an acceptable self-discharge rate needs little comment. If however a battery test indicates an unexpectedly poor result, before retiring the battery, it’s worth first checking the settings of your cycler. Batteries are often more reliable than their owners! Some possible battery problems are:

**Battery appears to have a substantially reduced capacity**

If a cycle test shows a battery to be very substantially below its nominal capacity there are several possible explanations.

1. **The battery is simply old or worn out.**
   Battery packs do not last for ever; if the whole pack is below-capacity but no particular cell is bad, the battery may of course simply be at the end of its life. Hydrides in particular are quite prone to suffering a reduced capacity after extended use. A low capacity battery may have lost some of its electrolyte through venting at some stage.

2. **The battery pack contains one (or more) bad cells.**
   If a cell suffers an internal short circuit (which is a fairly common failure mode for cells, possibly caused by reverse charging) the battery will simply appear to be one cell short. A battery with a bad cell may appear to charge satisfactorily, especially if slow charging, but little or no accumulation of charge will actually occur in the bad cell.

   During discharge, the cycler will constantly be monitoring the voltage of the battery to determine when it is flat. A bad cell may result in a reduced battery voltage. In this case, because the cycler cannot ‘see’ individual cells it may interpret the reduced battery voltage as meaning that the battery is exhausted, and terminate the discharge cycle at an earlier point than would otherwise be the case. The result is that the entire battery will appear to have a low capacity as a result of a single bad cell. This effect will be more evident with, for example, a 4-cell battery than one with a higher cell count. In a
particularly bad case, or if more than one cell is bad, the pack may appear to have no
useful capacity at all.

**What to do about reduced capacity.**
If a new battery is suffering from an unacceptably low capacity it should of course be
returned to the place of purchase for replacement. Used cells may benefit from the
maintenance procedures described in the following chapter. These may restore some of
the lost capacity.

**Pack has a high self-discharge rate.**
One possible failure mode of a battery is that it will appear to charge but will self
discharge very quickly, perhaps becoming fully discharged in less than one week. It may
also have a severely reduced capacity. There is very little that can be done about cells
in this condition except for checking that the test was carried out properly.

**Battery appears to be completely ‘dead’**
This condition would be detected by a charger behaving as though no battery is
connected to it. If the battery is tested, zero volts will be present across its wires. This
may indicate one of two possibilities; either an external cell connection has become
detached (e.g. internally broken wire or loose solder tag) or that a cell has failed
internally by going ‘open circuit’ (i.e. lacking electrical continuity).

**Locating bad cells**
A bad cell may be located by carefully penetrating its heat-shrink cell cover with pins
connected to a voltmeter. In this way the individual cell’s voltage may be measured as
the battery is cycled.

**Intermittent connections**
A battery that is intermittently ‘dead’ must be removed from service until the fault is
found. Such faults can be difficult to locate. If it is suspected that the fault may be
temperature related, it may be worth considering ‘cold soaking’ the battery it in a fridge
or even a freezer (wrap in a plastic bag to keep the battery from becoming damp) and
then testing it as it warms up. Include connectors and wiring in your investigation.
Black Wire Corrosion

Black wire corrosion (BWC) is a phenomenon where wire which is attached to batteries becomes corroded. It is so called because the usual place to find such corrosion is the negative lead of the wire where it connects to the battery. However BWC can also be found in positive (red) leads and it may also be found at some distance from the battery. Corrosion can spread a long way along a wire; a spread of 6 inches (200mm) is easily possible.

Left: The middle two of these leads have been affected by black wire corrosion. It is particularly obvious in the thicker black wire; notice the dark tone of the metal wire. Wire in this condition cannot be relied on to conduct electricity properly and will have become brittle. Wire in this condition cannot be soldered. Right: The printed circuit board inside this vintage transmitter has suffered from BWC. This would not have happened if the battery had been removed from the transmitter prior to storage. Although this transmitter is quite old, such corrosion can occur in much younger pieces of equipment.

The causes of BWC are not generally well understood. BWC seems to be more likely with batteries which are stored in a damp atmosphere. If you need to store your model in a garden shed for example, it would be wise to remove the battery from the model and keep it dry. Corroded wires will appear dull and will become brittle.

BWC is dangerous to models because the resistance of the wire increases, impairing electrical performance, and also because affected wire is liable to break rather easily. The only way to identify BWC is with a careful physical inspection of the wire’s metal conductor. Some of the wire’s insulation may need to be stripped back in order to carry out a thorough inspection.

Black wire corrosion must be checked for in any battery that is more than 2 years old and/or has been stored in damp conditions. Any battery affected with BWC must not be used in a model airplane and it should be replaced without delay, along with any associated wiring.
Replacing cells
If one cell within an otherwise good battery has gone bad, it may be replaced. The replacement cell should be of the same type and age. It should preferably also have had a similar usage pattern so that it does not become an ‘odd’ cell in a pack, which will tend to lead to the battery readily becoming unbalanced. However, be aware that a failed cell may be symptomatic of a battery which is close to being worn out; other cells may be in a similar condition. It is probably safer for your models to discard old batteries rather than repair them.

Safety-critical applications
Safety critical applications are those in which battery failure or premature exhaustion would create a hazard. Transmitter and receiver batteries are most definitely a safety critical application, since a failure of either will result in losing control of the model.

When to replace batteries in a safety-critical application
Some modellers routinely replace transmitter and receiver batteries after one or perhaps two years to guard against the possibility of an unexpected failure. This practice has much to recommend it, especially for hydride batteries which do not tend to have a long life span.

However, if a hydride battery is still in good working order, it does seem a little wasteful to replace it based purely on its age. Perhaps a better solution (and certainly a more economical one) may be to replace batteries when they show signs of a deteriorating performance, rather than simply because they have reached a certain age.

It is important to appreciate that just because a battery is new, it is not necessarily in perfect condition. Manufactured objects, including batteries, are most likely to fail at either the very beginning of their life, if a manufacturing defect is present, or else much later as they become worn out.

For this reason it is prudent to cycle a new battery at least once (and preferably more often) to test its condition and performance before trusting it in a transmitter or in a model as a receiver battery. Note that it may be necessary to cycle the battery a few times before its full capacity is gained.

In a safety-critical application such as a transmitter or receiver battery, a good rule of thumb is that a battery showing a capacity of less than 80% of its nominal capacity and/or an excessive rate of self-discharge should be retired. The reason for this is not the reduced capacity itself, because that can be taken account of in use, but because a substantially reduced capacity is a sure sign of degradation, thus indicating a greater likelihood of failure. Conversely, a battery in a non safety critical application, such as the battery in a low speed model boat, could still be perfectly acceptable even when well below 80 % of nominal capacity.
Lifespan of batteries
AA or ‘pencell’ cells, the size almost always used in transmitter and receiver batteries, have been growing in capacity with every year. Many years ago, 600mAh was about the highest capacity that was available. Now it is possible to find cells with a capacity of 2,500mAh or even greater.

This growth in capacity seems to be accompanied by, in some cases, a decrease in reliability and lifespan. Experience has shown that the higher capacity hydride batteries do tend to be less durable than similar, lower capacity examples. There also seems to be a tendency for higher capacity hydrides to lose capacity more quickly. For these reasons, when buying hydride batteries I generally choose those with a capacity of 2,000mAh or less, especially for safety critical applications.

Hydride lifespan
Hydride batteries are much less durable than nicad types. Used with care, a good quality hydride battery might have a service life in a transmitter or receiver of approximately 2 years.

Nicad lifespan
A good quality nicad battery may well last for more than 5 years. However, you may not wish to have batteries that old in a valued model. (At the time of writing, I have a 19 year old nicad battery, now installed in a domestic torch and still giving good service!) Ultimately, the decision as to how long to keep a battery in service depends on the particular circumstances such as the amount and type of use a battery has experienced, your attitude to risk, the history of the battery and so on. The decision is yours!

Invasive testing
The maintenance procedures described so far are all ‘non invasive’, in that access to the cells themselves is not required. However, in the case of a severely unbalanced battery, or one suffering badly from voltage depression, cycling may not effectively treat all the cells within the battery, since an individual cell could still contain a significant amount of charge even when the battery itself appears to be fully discharged.

In such cases, it may be beneficial to discharge each cell individually. To do this, the battery is first partially discharged. Then, to ensure that each individual cell is actually fully discharged, a small load such as a 1.5V bulb is connected to it. Electrical access to individual cells may be gained by means of dressmaking pins, carefully inserted through any heat-shrink plastic covering so that they touch the metal case of the cell. The use of a voltmeter will allow monitoring of the cell voltage during discharge. Nicad cells may be almost fully discharged, but to avoid damage, hydride cells should not be discharged below approximately 0.8V.

Once all the cells are discharged, they may be recharged by slow charging the whole battery. This procedure may be repeated up to three times, as required, although it is quite time-consuming.
Battery quality
The cells of an ideal battery would all be of exactly the same capacity and would have identical characteristics concerning their behavior under charge, discharge and in respect of any changes in their crystalline structure. However, in practice there will always be small variations between individual cells and this will cause them to each behave slightly differently when being charged and discharged. Also, if a battery is stored, the individual cells will each experience a different rate of self discharge.

The consequence of these factors will be that after a period of usage and/or time, the cells within a battery will inevitably be in unequal states of charge. A battery in this state is said to be ‘unbalanced’. A battery in an unbalanced condition is not suitable for discharging or for rapid charging. For example, if a severely unbalanced battery were to be fast charged, one or more of the cells may become severely overcharged long before other cells reached a fully charged state. Similarly, if an unbalanced pack were to be discharged, the cell containing the lowest amount of charge would become exhausted first, but the remaining charged cells within the pack would continue to drive current through the battery. The weakest cell(s) will therefore become reverse-charged and this may cause them damage.

Fortunately, it is usually possible to restore a battery to a balanced condition by using simple maintenance procedures which consists of charging and discharging cells in particular ways. The procedure is known as ‘balancing’, and can also be effective in erasing voltage depression. New batteries, or those fresh out of storage should always be assumed to be in an unbalanced condition.

Equalizing charge.
If it is suspected that a battery is in an unbalanced condition, the first requirement is to bring all of the cells to an equal state of charge. This process is also known as equalizing or leveling. The only safe way to achieve this is to fully recharge the battery at the slow charge rate to ensure that all cells within the pack safely reach a state of full charge. The battery is then said to be equalized and will be in a condition to be cycled.

Cycling an unbalanced battery
An unbalanced battery may be composed of cells which are not only in differing states of charge but which are also suffering unequally from the effects of voltage depression (crystal growth). Even after an equalizing slow charge, the battery will probably still not be in a satisfactory condition for use because of this. If nothing further was done, this may cause the cells to quickly assume unequal states of charge again once in use.

To fully balance the cells, it will be beneficial to cycle the pack at least once. The effect of cycling will be to break down the coarse crystalline structure (low capacity) inside the cell and convert it into a fine crystalline structure (high capacity). The process is also used to deal with the ‘memory effect’. This is probably best accomplished at lower rates of charge and discharge than might be used in a capacity test and 0.5C or possibly even less is suggested for this purpose. Take care not to discharge the pack excessively which could cause individual cells to become reverse charged.
After each cycle, record the capacity recovered from the battery, and repeat. Once the measured recovered capacity of the battery stops rising, it can be considered to have been restored to optimum condition, and may safely be fast charged. Up to perhaps three cycles may be necessary to achieve this. A noticeable improvement in cell capacity may sometimes be noticed by this cycling process. A cycler that is able to be programmed to complete more than one charge/discharge cycle would be particularly useful in such cases.

It is difficult to be specific on how often maintenance procedures such as those described here should be used. Sometimes it is possible to detect that a battery is in an unbalanced condition; under charging cells may be of different temperatures. It is probably fair to say that the less the ‘Top Tips’ (on the back cover) are followed the more cells will benefit from occasional maintenance. However, the tips are not hard and fast rules and in any case it is not always convenient to follow best practice.

Finally, it is only fair to acknowledge here that the extent of the need for maintenance is something of a subjective issue; some modelers do little more than simply use their cells, while others take great care of them, carrying out the sort of maintenance procedures detailed here in this chapter relatively frequently. Whatever viewpoint you form, a practical attitude has to be taken of maintenance issues because our batteries exist to serve us and not vice versa — if we spent all our time ensuring they were always in optimum condition we would probably get very little modeling done!
Chapter 15
Slow Charge Calculators

The two graphs in this chapter together offer a quick and convenient way to find an appropriate charging time for any combination of batteries up to 4,000mAh and charge currents up to 500mA. To use the graphs, simply select the combination of cell capacity and charge rate that is of interest, and find the sloping line at which they most nearly intersect. For clarity, examples are given for how to use each graph.

The charge period is given as a range, for example 10 – 14 hours. Calculating a slow charge time is always going to be a slightly subjective endeavor, since there are many variables involved such as actual cell capacity, proportion of battery energy wasted as heat and so on. It is recommended that the higher charge time is used unless the battery is known to be significantly less than fully discharged.

Left: For slow charging, a charger like this one may not be the best tool. Right: Slow chargers like this one that are often supplied with RC equipment. However, if charging a non standard battery, it can be difficult to know the optimum charge time.

Notice that where a range of times is indicated the lower figure (in this case 10 hours) represents the theoretical charge time, and the upper figure (14 hours in this case) includes an appropriate additional charging period to compensate for charging inefficiencies etc. Please note that although charge rates above C/10 are shown, these are not considered to be slow.

If you wish to manually charge at rates above C/10, proceed carefully, ensuring that the cells are fully discharged before charging and that maximum charge times are not exceeded. The dangers of overcharging are amply described in the previous chapters and need not be elaborated on again here. Note that as the charge rate increases, the amount of overcharge that may safely be tolerated reduces.
This graph is intended for use with batteries up to 1,400mAh and chargers up to 140mA.

To use this graph, simply select the combination of cell capacity and charge rate that is of interest, and find the sloping line at which they most nearly intersect. The red lines for example, show that for the combination of a 500mAh battery and 50mA charger, a charging period of 10-14 hours would be appropriate.
This graph is intended for use with batteries up to 4,000mAh and chargers with a charging rate up to 500mA.

To use this graph, simply select the combination of cell capacity and charge rate that is of interest, and find the sloping line at which they most nearly intersect. The red lines for example, show that for the combination of a 2,400mAh battery and a charge rate of 300mA, a charging period of 8 -10 hours would be appropriate.
Chapter 15
Fast Charge Calculators

The graphs on these two pages enable us to quickly predict approximate charge times for fully discharged cells. The first graph is intended for cells up to 1,200mAh, and the second graph for cells up to 4000mAh in capacity. Please note that actual charging times will depend both on the charger used and the charging efficiency of the cells and are likely, in practice to be slightly longer than indicated.

How to use the calculator – example
Suppose you needed to charge an 800mAh battery, and wanted it ready in about 30 minutes. This first graph would be suitable for this situation as it covers cells of this capacity. The solid red line on the graph shows us that a charge rate of about 1.6 Amps would have the battery ready in time, and that this current would be about 2 C for this battery. Alternatively, the broken red line shows the (lower) current required to charge the battery in 40 minutes. This is 1.2 Amps.
Suppose it was required to charge a 2,400mAh battery in 30 minutes. We would use the second graph for cells of this capacity. This shows us that a charge rate of nearly 5 Amps would have the battery ready in time, and that this current would be about 2 C for this battery.

The arrows at the top of the graph demonstrate that as charge current is increased, the saving in charge time becomes progressively smaller. For example, increasing the charge rate of a nicad from 1.5C to 2C saves 10 minutes, whereas increasing again from 2C to 2.5C saves only a further 6 minutes. An awareness of this 'law of diminishing returns' may help you avoid the temptation to select excessively fast charge rates!
This section summarises some of the most important points about working with hydride and nicad batteries. For more complete guidance, read this guide!

**Charging:**
- Always slow charge new cells for the first charge.
- Treat stored cells as though new when bringing back in to service.
- Do not charge cells excessively quickly - cells may become hot.
- Do not over-charge cells when fast charging.
- Try to avoid excessive slow charging.
- Do not charge hot cells - as above; wait for them to cool before recharging.

**Discharging:**
- Do not over-discharge batteries - weaker cells may become reverse charged.
- Respect discharge C limits.
- Prevent short circuits.
- Provide plenty of cooling ventilation for electric power batteries.
- Cycle batteries occasionally.

**Storing batteries**
- If convenient, leave nicad batteries in a discharged condition between uses.
- Store nicad cells in a fully discharged condition.
- Always store hydride cells with some charge.
- Cycle stored cells occasionally.
- Keep batteries in a dry atmosphere.

**Safety**
Prevent short circuits.
Do ensure connectors are insulated to prevent short circuit in handling or storage
Keep all batteries out of the reach of children.
Don't carry batteries in pockets. They might short against coins or keys. Ouch!

**Extending the life of cells**
Use fully charged batteries soon after charging
Avoid fully discharging hydride batteries
Check charger settings carefully before charging - every time.
Appendix 2
Battery Test report

The form on this page may be printed out and used to assist with testing batteries. Make sure you select only this page for printing.

<table>
<thead>
<tr>
<th>Battery name/identification</th>
<th>Voltage, number &amp; type of cells</th>
<th>Stated battery capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V</td>
<td>mAh</td>
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</table>

External inspection - check condition of cells, wiring and connector. Note and correct any defects.

**Charge battery prior to testing its capacity (fast charge & equalize cells or carry out charge at low rate)**

Initial charge rate.................mA to delta peak
Cells equalized at.................mA start time ................ finish ............
Or for low rate charge:
Charge start (time & date)........ Charge finish ............

**Test 1: Capacity test (repeat 1-3 times as required)**

Discharge rate.................mA Charge rate if testing more than once .....mA
Capacity delivered (1) .................mAh (2) .................mAh (3).................mAh

**Recharge prior to charge retention test**

Charge rate used .......................mA
Charge quantity supplied ...............mAh (if known)

Cells equalised at.................mA
Start time ................ date ............
Finish time ................ date ............

**Test 2: Charge retention test**

Test date ....................
Number of days set aside ............
Discharge rate .......................mA
Capacity recovered .....................mAh
Loss of capacity per day ............
### Graph, table & drawing finder

<table>
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<td>(g) = graph, (t) = table, (d) = drawing</td>
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