COMMERCIAL BATTERY INFORMATION

Batteries and Charging

The availability of solid state equipment makes it practical to use battery power under portable or emergency conditions. Hand held transceivers and instruments are obvious applications but even fairly powerful transceivers (100 W or more output) may be practical users of battery power (for example, emergency power for the home station for ARES operation).

This paper is intended for use by anyone who needs to provide DC power to their equipment using batteries and wants to understand how different types of batteries can be used to satisfy their power needs. Several types of commercially available primary and secondary cells will be discussed. There is a spread sheet, at the end of the paper that will sum up the different cell types, their voltages, current capacities and expected life spans.

A battery is a group of cells. These cells may be connected in series to give some desired multiple of the cell voltage. Series strings may be connected together in parallel to provide a desired current capacity or desired total power storage capacity. The chemical composition of the cell determines it's terminal voltage (i.e. voltage at the terminals) and power density capability [i.e. power storage capability in ampere hours (AHr)], the cell's internal structure determines it's maximum current flow capability. There are two general types of cells: The "primary" cell which is not rechargeable is used one time and discarded, the "storage" (or "secondary") cell may be recharged (and used) many times.

Internal Resistance
Cell internal resistance is very important to handheld transceiver users. The internal resistance of each cell is in series with the battery's output and therefore reduces the available battery voltage at high discharge currents. The result is reduced transmitter output power and power wasted in the cell itself by internal heating. Cell construction techniques and chemistry determine a cell's internal resistance characteristics.

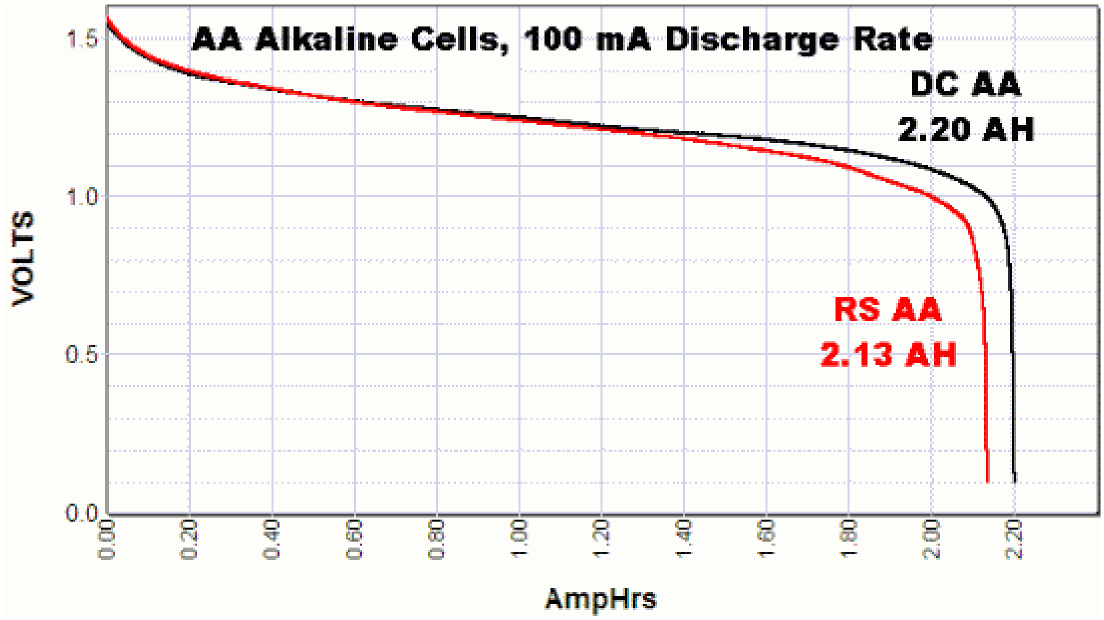
PRIMARY CELLS

One of the most common primary cell types is the **Carbon-Zinc**, or **Leclanché** cell that we used to commonly use in flashlights and toys, in which chemical oxidation occurs during discharge. This chemical oxidation converts the zinc into salts, and produces electricity. The oxidation essentially only occurs when current is required. However, a slight amount of chemical reaction does continue, so stored batteries eventually degrade or use so much of the outer shell (in the chemical reaction) that they leak chemicals outside of the cell. The time taken for degradation with no current drain is called shelf life. The carbon-zinc cell has a nominal voltage of 1.5 V (when new). Larger cells are capable of producing more current and therefore have less voltage drop than smaller cells. Heavy-duty and industrial cells usually have a longer shelf life. The carbon zinc cell is now mostly supplanted by the alkaline cell, which has better discharge characteristics and will retain more capacity at low temperatures.

The **Alkaline-Manganese cell** typically has an ampere hour capacity of about twice that of the same size carbon-zinc cell. Its nominal voltage when new is also 1.5 V, however, under use it's "nominal" voltage is 1.2 V. This cell also uses it's outer shell in the chemical reaction to produce it's power, and will eventually leak.

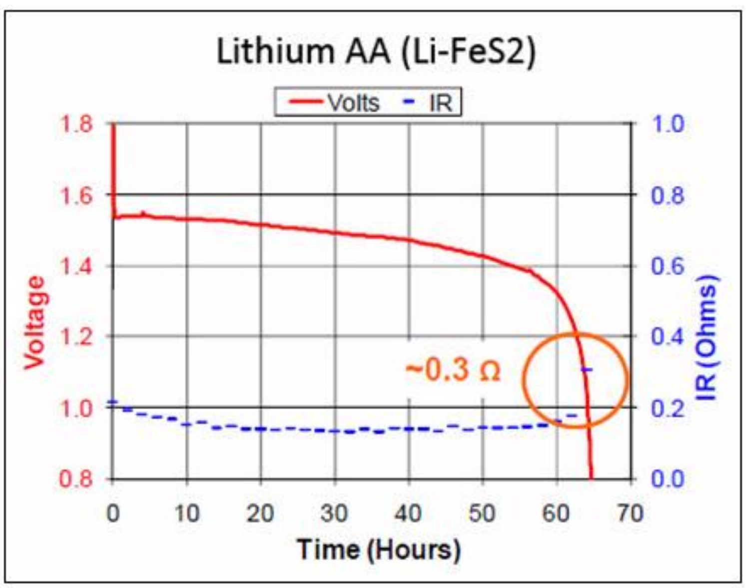
To clean corroded battery terminals in toys, mix White Vinegar with water (equal parts) and use a Q-tip to clean it, or mix 2 tablespoons of baking soda in a bowl with water and clean the terminals using a Q-tip that has been wet with baking soda paste and allow it to settle for five minutes. Use a damp cloth to wipe the terminals and dry them with a clean cloth. You should then let it dry out before using it again. The white stuff from the battery is caustic so use rubber gloves.

Lithium primary cells have nominal voltages of either 1.75 or 3 V per cell (depending on chemistry) and by far the best capacity, discharge, shelf life and temperature characteristics. Their disadvantages are high cost and the fact that they cannot be replaced by other cell types in an emergency. Additionally, because they have such high power densities they may catch fire or explode if punctured. One of the benefits of Lithium primary cells is that they do not leak, even when totally depleted.



Discharge Curves for AA Alkaline Cells

Lithium Iron Disulfide (Le/FeS_2) cells are presently produced in the AA size. They have an open circuit voltage of 1.75 V, and provide a fairly flat working voltage of 1.5 V over their discharge life. They provide improved performance under high rate discharge, high pulse drains and better operating characteristics in low temperature environments, compared to alkaline-manganese cells.



Voltage and Internal Resistance on Discharge

Lithium Manganese Dioxide (Li/MnO_2) cells have an open circuit of 3.0 and working voltage of 2.8 V. These cells provide high current and high pulse capability, and have a flatter discharge curve than alkaline-manganese cells. These cells are commonly found in the 2/3 “A” sized CR123 package for 3 V and in MN1604 sized batteries for 9 V applications.

Lithium/Sulfur Dioxide (Li/SO_2) cells have an open circuit of 3 V and working voltage of 2.6 V and a flat discharge curve. These cells can be used over a wide temperature range. They perform very well under pulse loads, at very low temperatures, and under high power drains. Although available in single cells we only use them in the military style BA-5590 battery. These batteries have so much lithium that shipment is regulated by DOT even when not connected in the circuit. They are subject to exploding when punctured.

Silver oxide (1.5 V) and **Mercury** (1.4 V) batteries are very good where nearly contact voltage is desired at low currents for long periods. Their main use (in subminiature versions) is in hearing aids and watches, though they may be found in other mass produced devices.

SECONDARY OR RECHARGEABLE BATTERIES

Many of the chemical reactions in primary cells are theoretically reversible if current is passed through the battery in the reverse direction. For instance, zinc may be plated back onto the negative electrode of a carbon-zinc cell.

Primary cells should not be recharged for two reasons: It may be dangerous because of heat generated within sealed cells, and even in cases where there may be some success, both the charge and life are limited. In the, carbon-zinc example, the zinc may not re-plate in the locations that had been oxidized.

Pinholes in the case may still occur causing fluid leakage that could damage the equipment the cells are in. (One type of alkaline cell is rechargeable, and is so marked).

Secondary cells, unlike primary cells, may be manufactured with several different energy densities and current capacities in the same form factor. For instance, the very common "Sub C" sized

Nickel Cadmium cell found in most NiCd battery powered tools, can be purchased from 600 up to 2500 mAHr capacity, and the "18650" sized LiIon, found in many LiIon powered tools, can be purchased with from 1400 to 3400 mAHr capacity. So, when you read an advertisement for a company that repairs your power tool battery pack and gives it more power than the original manufactured model, you now know that it can actually be done, by using higher power density cells.

Nickel Cadmium,
The most common type of smaller rechargeable cell is the nickel-cadmium (NiCd). The NiCd cell is capable of very high discharge rates, and contains much more capacity than the same size alkaline cell. The NiCd has a working voltage of 1.2 V per cell. Carefully used, they are capable of 500 or more charge and discharge cycles. These cells are capable of discharge rates equal to ten times the battery's capacity (i.e. 10C where "C" is the battery capacity) for periods up to 40 seconds. Another major feature of these cells is the propensity to self discharge. In fact these cells will completely discharge themselves in about 30 days.

For best life, the NiCd cell should be discharged to no more than 80% of full discharge. Where there is more than one cell in the battery, the cell that is most discharged (i.e. weakest) may suffer polarity reversal as current flows through it backwards while the other cells in the battery pack continue their discharge cycle. Cell reversal normally results in the cell becoming a short circuit and may result in the seal rupturing. All storage batteries have discharge limits. NiCd cells should not be discharged to less than 1.0 V per cell.

The NiCd cell is the undisputed king of cell types for high discharge current capability. Also, the NiCd maintains this low internal resistance throughout its discharge curve, because the specific gravity of its potassium hydroxide electrolyte does not change. Next in line is probably the alkaline primary cell.

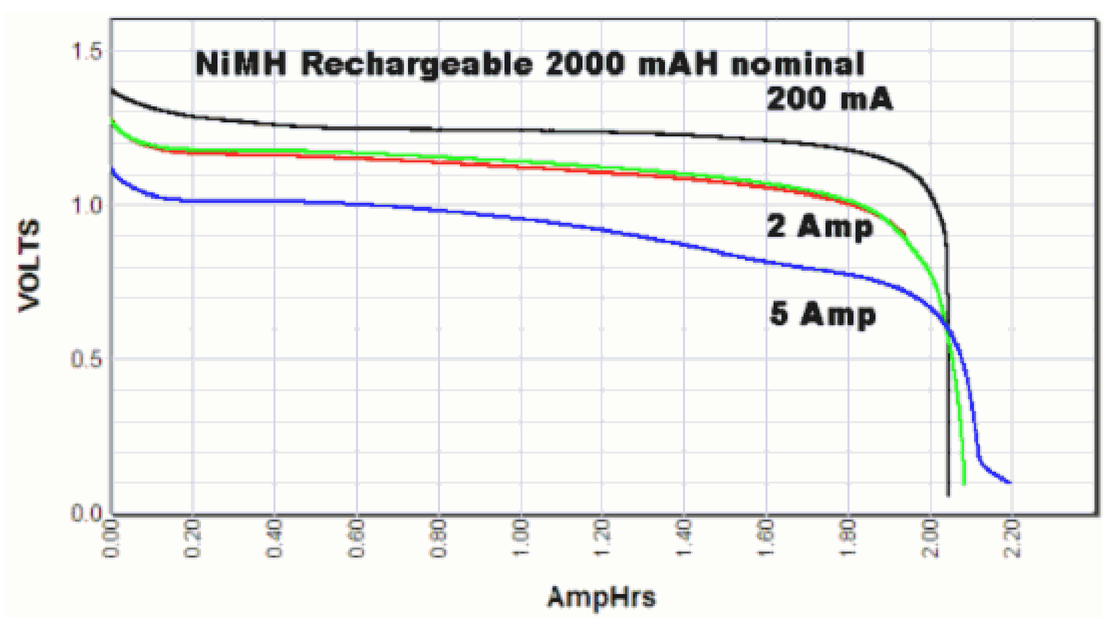
NiCd cells are known for their acquisition of "memory". This is a term that is applied to NiCds that have been discharged to a certain point several times (e.g. used for shaving with an electric razor for 5 minutes every day) before being recharged. The battery will soon remember how much capacity is needed and not be able to provide power after that capacity is reached. To avoid memory the user should use the batteries until they are discharged to their 80% depth before recharging them.

Charging should be done with the original manufacturer's charger. If that isn't available, it is recommended to charge at no more than 1.55 V per cell using a constant current rate of C/10 for no more than 16 hours. During charging these cells stay at room temperature, but their temperature increases dramatically as they approach their fully charged state. A 3 degree temperature rise normally indicates a fully charged cell. Further charging after that temperature increase may cause the cell to vent.

NiCd cells should be stored DISCHARGED. That is, if you will not be using the battery for a while, you should try to discharge it before putting it away. Trickle charging between long periods of inactivity is not advisable. Charging should only be done just before the battery is going to be used.

Nickel Metal Hydride

The nickel metal hydride is a chemistry that was developed as a "green" alternative to the NiCd. Fully charged, open circuit voltage is 1.4 V. Working voltage is 1.2 V per cell. NiMH has a capacity that is 2 to 3 times that of NiCd, but must be charged and discharged at lower rates than NiCd. These cells are also sensitive to and may be degraded by pulse discharges. NiMH cells also have a high self-discharge rate (between 0.5& 4% per day). NiMH have been tested and proved to provide useful power capability after 1,000 charge and discharge cycles.



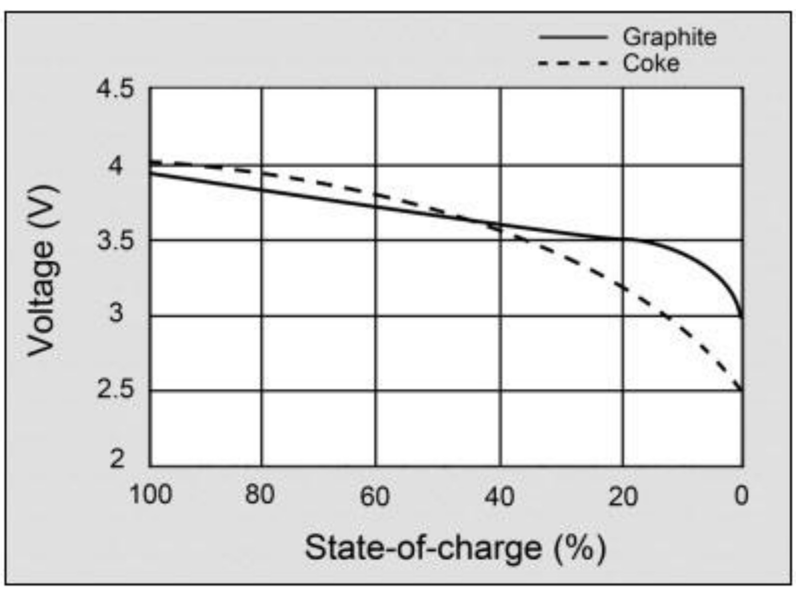
Discharge Curves for AA NiMH Cells

NiMH cells should be charged using their manufacturer's charger. NiCd chargers are not appropriate for this chemistry. Trickle charging can be done at a timed C/10 rate. NiMH cells should be stored charged. Therefore, when storing these batteries one should periodically charge them, but don't trickle charge them.

Lithium Ion

LiIon cells have evolved into a family of types of LiIon. The most commonly used chemistries are **Lithium Cobalt Oxide** ($LiCoO_2$), **Lithium Iron Phosphate** ($LiFePO_4$)(aka **LFP**), **Lithium Manganese Oxide** (**LMO**), and **Lithium Nickel Manganese Cobalt Oxide** (NMC).

Their typical working voltage is 3.6 V (3.2 V for LFP). Depleted cells measure 3.0 V. LiIon cells typically provide useful power capability from 400 to 1200 charge and discharge cycles. However, they degrade internally and typically last no more than three (3) years from the date of manufacture, whether they are used or not. (NOTE: Research is underway to increase the useful lifetime of LiIon using self healing electrodes but is still a few years away.) LFP chemistries, on the other hand, have a normal shelf life of 10 years. LiIon cells do not develop a memory. The cells contain no Lithium metal and are not regulated by the Department of Transportation. However, they are very volatile and can explode or catch fire if punctured or completely discharged.



Voltage Discharge Curve of Lithium-Ion Cell

Charging for these cells is very complicated, requiring careful control of the current and voltage, as well as monitoring cell strings and sometimes each cell during charging. Charging should only be performed using the manufacturer's charger. If the chargers do not automatically shut off, the battery should be removed from the charger when charging is complete. Charging of normal cells typically takes less than one hour.

LiIon cells prefer to not be discharged below 30% and are very sensitive to over discharge. Voltages below 2.75 V per cell can damage the cells. So equipment using them should be designed to automatically turn off when cell voltages reach the standard cut-off voltage per cell for that chemistry. Self discharge rate is generally less than 8% per month. LiIon cells are completely ruined if discharged 100%.

LiIon batteries should be stored between 50 – 35% of charge at temperatures below 77^0F. So, do not keep them on a constant trickle charger so they will be ready for use.

One manufacturer of LFP 12 Vdc batteries for use in motorcycles is Shorai. Their designation is "LFX" battery.

Silver Zinc (AgZn)

This chemistry provides high energy density, and the batteries operate at relatively high discharge rates. They have a lower self discharge than NiCd or Lead-Acid. Life cycling has found a decreased capacity after as little as 50 cycles. AgZn cells should be stored charged.

Lead Acid (Pb/PbO_2)

The most widely used rechargeable cell is the lead-acid type because of it's high capacity and low price. This cell has a nominal voltage of 2.1 V per cell. In automotive service, the cell is usually discharged partially at a very high rate, and then recharged promptly while the alternator is also carrying the electrical load. Conventional auto batteries should not be discharged to 1.75 V per cell (10.5 V for a 12 V battery) as that will drastically reduce the number of discharge cycles and storage capacity, and may also cause reduced capacity. These cells are also sometimes referred to as flooded cells, as the electrolyte is a liquid with the consistency of water and the chemical composition of water and Sulfuric acid.

These cells should be stored in a charged state and can be trickle charged for long periods. Trickle charging voltages are normally about 2.32 volts per cell. Insure that the lead plates are completely covered with water. Uncovered plate sections can become unable to take a charge or provide current. Charging is done using constant voltage chargers. Set the charger to no more than 2.4 V per cell. These cells prefer slow charging with current limiting to C/10 as the fastest. Formation of gas bubbles indicates the battery is reaching a full state of charge. **A totally depleted battery** should be charged very slowly to allow the battery to absorb as much energy as possible.

The most attractive battery for extended high-power electrical applications is the "deep-cycle" battery, which is intended for use in powering electric fishing motors and the accessories in recreational vehicles. When properly cared for, they may be expected to last more than 200 cycles. They are heavier than other non deep cycle batteries because their plates are thicker and extend farther down towards the cell bottoms. They often have lifting handles and screw terminals, as well as the conventional truncated-cone automotive terminals.

The lead-acid cell, which is finding popularity in belt-hung battery packs, is pretty close to the alkaline cell for internal resistance, but only at full charge. Unlike the NiCd, the electrolyte in the lead-acid cell enters into the chemical reaction. During discharge, the specific gravity of the electrolyte gradually drops as it approaches water, and the conductivity decreases. Therefore, as the lead-acid cell approaches a discharged state, the internal resistance increases. For the belt pack, larger cells are used (approximately 2 Ah) and the internal resistance is consequently reduced.

When flooded batteries are stored for long periods of time the electrolyte may striate leaving water on the top and a more concentrated acid in the lower part of the chamber. When this happens the battery should be moved around to enable the electrolyte to become more homogeneous before charging.

Lead-acid batteries with liquid electrolyte usually fall into one of three classes: conventional, with filling holes and vents to permit the addition of distilled water lost from evaporation: high-rate charge or discharge: maintenance-free, from which gas may escape but water cannot be added. Generally, the deep-cycle batteries have filling holes and vents.

Gel Cell
Lead-acid batteries are also available with gellied electrolyte. Commonly called gel cells or SLA (Sealed Lead Acid), these may be mounted in any position if sealed, but some vented types are position sensitive. Charging and discharging characteristics are similar to flooded lead acid batteries. Trickle charging is done at about 2.23 V/cell. These batteries are also referred to as "Maintenance Free" as there are no user accessible vents.

AGM
The Absorbent Glass Mat or AGM is a newer design and suspends the electrolyte in a specially designed glass mat. This offers several advantages to lead acid systems, including faster charging and instant high load currents, in addition they are leak proof, vibration resistant, position insensitive and maintenance free. An AGM is usually not very large and has typical capacities of 30 to 100 Ah. These cells are capable of depth of discharge to 80% without degradation.

These cells should be charged with a constant voltage charger that is current limited to a C/10 rate. However, they can be fast charged at a C/2 rate if properly controlled. Normal charge voltages can be as high as 2.4 V/cell. Float charge voltage should be about 2.25 V/cell. Since the batteries are sensitive to ambient temperatures you should consider using a smart charger similar to a "Battery Tender" which uses ambient temperature to determine charging voltage.

Fuel Cells
A fuel cell is a device that uses a chemical reaction with oxygen or another oxidizing agent to create electricity. Hydrogen is the most common fuel, but hydrocarbons such as natural gas and alcohols like methanol are sometimes used. Fuel cells are different from batteries in that they require a constant source of fuel and oxygen/air to sustain the chemical reaction. Fuel cells produce electricity continually as long as fuel is supplied. A typical 100 W H_2 fuel cell would use about 1.5 L/min and cost $1600. Service life is about 7,300 hours.

They are made up of three adjacent segments: the anode, the electrolyte, and the cathode. Two chemical reactions occur at the interfaces of the three different segments. The net result of the two reactions is that fuel is consumed, water or carbon dioxide is created, heat is created, and an electric current is created which can be used to power electrical devices. The electrolyte substance usually defines the type of fuel cell. A typical fuel cell produces 0.6 to 0.7 Vdc under full load.

In the typical hydrogen-oxide proton exchange membrane fuel cell (PEMFC) design, a proton-conducting polymer membrane (the electrolyte) separates the anode and cathode sides.

There are also fuel cells that use hydrocarbons for fuel including; diesel, methanol (direct-methanol fuel cells and indirect methanol fuel cells) and chemical hydrides. The waste products with these types of fuel are carbon dioxide and water.

Solid oxide fuel cells (SOFCs) use a solid material, most commonly a ceramic material called yttria-stabilized zirconia (YSZ) as the electrolyte. Because SOFCs are made entirely of solid materials, they are not limited to the flat plane configuration of other types of fuel cells and are often designed as rolled tubes. They require high operating temperatures (800–1000 °C) and can be run on a variety of fuels including natural gas. The high temperatures involved require one to provide for the removal of that heat. It can be used for other purposes (e.g. to create steam) but is a bit impractical for the typical home hobbyist.

	Operating temp. (°C)	Fuel	Electrolyte
PEMFC	40-90	H_2 (/CO_2)	Polymer
AFC	40-200	H_2	KOH
DMFC	60-130	Methanol	Polymer
PAFC	200	H_2 (/CO_2)	Phosphoric Acid
MCFC	650	CH_4, H_2, CO	Molten Carbonate
SOFC	600-950	CH_4, H_2, CO	Solid Oxide

Noble metals — Noble metals/non-noble metals — Non-noble metals

Operating Temperatures vs. Electroyte

Special Considerations and Precautions

In addition to the precautions given above, the following precautions are recommended.

Gas escaping from storage batteries may be explosive. Keep flames or lighted tobacco products away.

Dry-charged storage batteries should be given electrolyte and allowed to soak for at least half an hour. They should then be charged at a C/10 rate. The capacity of the battery will build up slightly for the first few cycles of charge and discharge, and then have fairly constant capacity for many cycles. Slow capacity decrease may then be noticed.

No battery should, be subjected to unnecessary, heat, vibration or physical shock. The battery should be kept clean. Frequent inspection for leaks is a good idea. Electrolyte that has leaked or sprayed from the battery should be cleaned from all surfaces. The electrolyte is chemically active, electrically conductive, and may ruin electrical equipment. Acid may be neutralized with sodium bicarbonate (baking soda), and alkalis may be neutralized with a weak acid such as vinegar. Both neutralizers will dissolve in water, and should be quickly washed off. Do not let any of the neutralizer enter the battery

BATTERY CAPACITY

The common rating of cell capacity is ampere hours (Ah), the product of current drain and time. The capacity is the amount of power a cell can provide until it is considered depleted. Because most cell output voltages drop as power is used, the depleted state is commonly noted by the cell's voltage. The symbol “C” (capacity in Ampere hours) is commonly used. The discharge rate is expressed in terms of C divided by the time to discharge; C/10 for example, would be the current rate for 10 hours of continuous discharging. The value of C changes with the discharge rate and might be 110 at 2 A, but only 80 at 20 A.

Sealed primary cells usually benefit from intermittent (rather than continuous) use. The resting period allows completion of chemical reactions needed to dispose of by-products that occur during discharging.

The output voltage of all batteries drops as they discharge. When some cells are used with handheld transceivers, it is not uncommon to have lower output power, and often to have the low battery indicator come on, even with fresh cells. When this happens switch to cells that have a higher discharge current capability.

Discharge Voltages

Cell chemistry dictates a cell's voltage reading when it is fully discharged. Typical cell endpoint voltages are:

Alkaline ($ZnMnO_2$)	-- 0.8 V per cell
Nickel Cadmium (NiCd)	-- 1.0 V per cell
Lead Acid ($PbPbO_2$)	-- 1.8 V per cell
Lithium Sulfur ($LiSO_2$)	-- 2.0 V per cell
Lithium Ion (LiIon)	-- 3.0 V per cell
Nickel Metal Hydride (NiMH)	-- 0.9 V per cell

Batteries subjected to cold temperatures have less of their capacity available, and some attempt to keep a battery warm before use is worthwhile. A battery may lose 70% or more of its capacity at cold extremes, but it will recover with warmth. All batteries have some tendency to freeze, but those with full charges are less susceptible to freezing. A fully charged lead-acid battery is safe to — 30°F (—26°C) or colder. Storage batteries may be warmed somewhat by charging.

Blow torches or other flames should never be used to heat any type of battery.

In addition to battery depletion a practical discharge limit also occurs when a low battery voltage will no longer satisfactorily operate the load device. Much gear intended for "mobile" use (with 12.6 V car batteries) may be designed for an average of 13.6 V (typical charging voltage is between 13.8 V and 14.5 V) and a peak of perhaps 15 V, but operates poorly below 12 V. For full use of battery charge, the gear should operate well (if not at full power) on as little as 10.5 V with a nominal 12 to 13.6 V rating.

Somewhat the same condition may be seen in the replacement of Alkaline cells by NiCd cells. Eight Alkaline cells will give 12 V, while 10 of the same size NiCd cells are required for 12.4 V. If a 10-cell battery holder is used, the equipment should be designed for 16 V in case Alkaline cells are used.

Discharge Planning

Transceivers usually drain a battery at two or three rates: one for receiving (i.e. transmit standby) and one for key-down or average voice transmit. Considering just the first and last of these (assuming the transmit standby is equal to receive), typical two-way communication would use the low rate 3/4 of the time and the high rate 1/4 of the time. The ratio may vary somewhat with voice. The user may calculate the percentage of battery charge used in an hour by the combination (sum) of rates. If, for example, 20% of the battery capacity is used in an hour, the battery will provide five hours of communications per charge. In most actual traffic the time spent listening will be much greater than that spent transmitting. For this calculation, cell end point voltage should be a consideration when the battery pack voltage can drop below the equipment minimum operating voltage. The battery pack may not be fully depleted before the equipment stops working because it’s operating voltage isn’t high enough.

General Charging/Discharging Requirements

The rated full charge of a cell, is expressed in ampere-hours. No cell is perfect, so more charge than this must be applied to the cell for a full charge. If, for instance, the charge rate is 0.1 C (the 10 hour rate, also written C/10), 12 or more hours may be needed to reach full charge.

NiCd cells differ from the lead-acid types in the methods of charging. It is important to note these differences, since improper charging can drastically shorten the life of a cell. Charging should be at approximately 1.4 V per cell and the charger should be the constant current type. NiCd cells have a flat voltage-versus-charge characteristic until full charge is reached; at this point the charge voltage rises abruptly and the cell temperature dramatically increases. With further charging, the electrolyte begins to break down and oxygen gas is generated at the positive (nickel) electrode and hydrogen at the negative (cadmium) electrode. Since the cell should be made capable of accepting an overcharge, battery manufacturers typically prevent the generation of hydrogen by increasing the capacity of the cadmium electrode. This allows the oxygen formed at the positive electrode to reach the metallic cadmium of the negative electrode and re-oxidize it: During overcharge, the cell is in equilibrium. The positive electrode is fully charged and the negative electrode less than fully charged, so oxygen evolution and recombination "wastes" the charging power being supplied.

In order to ensure that all cells in a NiCd battery reach a fully charged condition, NiCd batteries should be charged at about the C/10 rate. This level is about 50 mA for the AA size cell. This is the optimum rate for most NiCds since C/10 is high enough to provide a full charge and good charge efficiency, yet it is low enough to prevent over charge damage.

Although fast-charge-rate (3 to 5 hours) chargers are available they should be used with care. The current delivered by these units is capable of causing the generation of large quantities of oxygen in a fully charged cell. If the generation rate is greater than the oxygen recombination rate, pressure will build in the cell, forcing the vent to open and the oxygen to escape. To prevent overcharge from occurring, fast-rate chargers should have automatic charge limiting circuitry (measuring either cell voltage, cell temperature change or both) that will switch or taper the charging current to a safe rate as the battery reaches full charge. Over charging NiCds in moderation causes little loss of battery life. However, continuous over charge, may generate a voltage depression when the cells are later discharged.

At the C/10 rate charging of NiCd cells should be terminated after 15 hours. Better results are obtained when charging current is reduced to about C/20 or charging is stopped as the 1.43 V/cell terminal voltage is reached.

Gelled-electrolyte lead-acid batteries provide 2.1 V/cell when fully charged. Effective charging is between 2.3 and 2.4 V/cell. Damage results if they are charged above 2.4 V/cell. (Avoid constant current or trickle charging unless battery voltage is monitored and charging is terminated when a full charge [2.4 V/cell] is reached.) Voltage limited charging is best for these batteries. A proper charger maintains a safe charge current level until 2.3 V/cell is reached (13.8 V for a 12 V battery). Then, the charge current is tapered off until 2.4 V/cell is reached. The battery may be safely maintained at the "float" level, 2.3 V/cell. Thus, a 12 V gel cell battery can be "floated" across a regulated 13.8 V charger. For lead-acid batteries, a timer may be used to run the charger to make up for the recorded discharge, plus perhaps 20%. Some chargers will switch over automatically to an acceptable standby charge.

Deep-cycle lead-acid cells are best charged at a slow rate, while automotive may safely be given quick charges. This depends on the amount of heat generated in each cell and cell venting to prevent pressure build-up. Some batteries have built-in temperature sensing that is used to stop or reduce charging before the heat rise becomes a danger. Quick and fast charges do not usually allow gas recombination, so some of the battery water will escape in the form of gas. If the water level falls below a certain point, acid hydrometer readings are no longer reliable.

One Final Note

Always remove batteries from equipment if you are not going to use it for awhile, or if your going to ship the equipment. All batteries should be stored in non-conductive materials to prevent short circuits.

EXTRA AVAILABLE INFORMATION

The following web site is Duracell's site where a lot of the information was gathered for the primary cells. http://ww2.duracell.com/en-US/Global-Technical-Content-Library/Product-Data-Sheets.jspx?icn=Prim/PrimNav/Product-Data-Sheets&cc=Primary

The following web site is for the Battery University and has lots of info on all kinds of cells as well as maintaining rechargeable batteries. http://batteryuniversity.com/learn/

In general, Home Depot, and Lowes will recycle most rechargeable batteries. Car batteries may be taken to Walmart or Costco for recycling. The following website may be used to find out where to take your worn out cells. http://www.call2recycle.org/

A list of all cell types including some of the chemistries used in those cell types, typical capacities and typical uses is available at the following website: http://en.wikipedia.org/wiki/List of battery sizes .

A sample of a commercially available H_2 fuel cell.

del reference	FCP30	FCP50	FCP75	FCP100	FCPc
Number of cells	12	20	30	40	Custom
Nominal power	30W	50W	75W	100W	2.5W/cell
Maximum power	40W	67W	100W	133W	3.3W/cell
Voltage range	7.2-11.2V	12-19V	18-28V	24-38V	-
Current (at 0.6V/cell)	4.25 Amps	4.25 Amps	4.25 Amps	4.25 Amps	4.25 Amps
Dimensions	84x115x75	116x115x75	156x115x75	196x115x75	XXXx115x75
Gross weight (stack+fan+valve)	750g	900g	1100g	1300g	-

FC operating conditions	
Reactant gases	H_2/air
Operating temperature	5°C-30°C
Max FC temperature	55°C
Fuel cell cooling	Air cooled
Humidification	Self humidified
H_2 supply pressure	0.2-0.3 barg
H_2 purity	99.995% dry

Controller specifications	
Power source	Self powered by FC
Minimum operating voltage	7V
Max temperature cut off	60°C
On/Off/Menu control	Single state push button
Weight	165g
Outputs	12V fan power + 12V purge FC voltage + current Controller power consumption FC temperature, Valve position Alarm, Short Circuit Manager