A.R.E.S. Battery Safety
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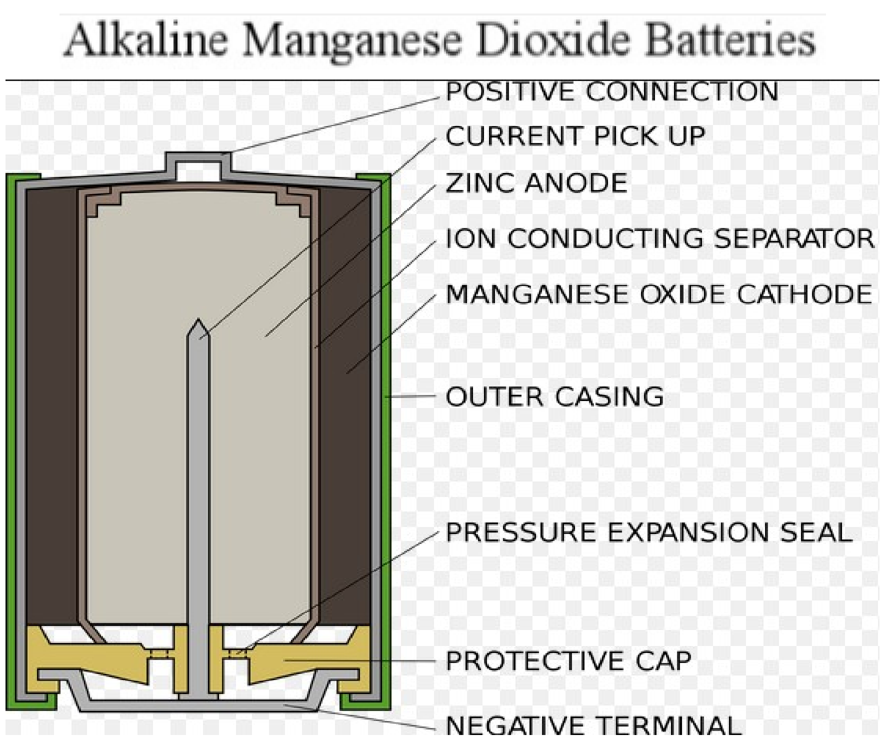
Batteries are everywhere!!! For some things, batteries are a primary power source. For some things, batteries are a back up power source. Is anyone capable of naming all of the things batteries are used in?

Amateur radio uses batteries. Where would amateur radio be without batteries? Batteries are so prolific in our daily lives and in amateur radio, it would be irresponsible and unthinkable to not cover the topic of battery safety.

This will only attempt to cover some of the more common batteries used in everyday life and in amateur radio. Batteries are made of many various chemicals and compounds, but I will address these: Alkaline, Lead Acid, Nickel Cadmium (NiCAD), Nickel Metal Hydride, and Lithium Ion.

Alkaline Batteries

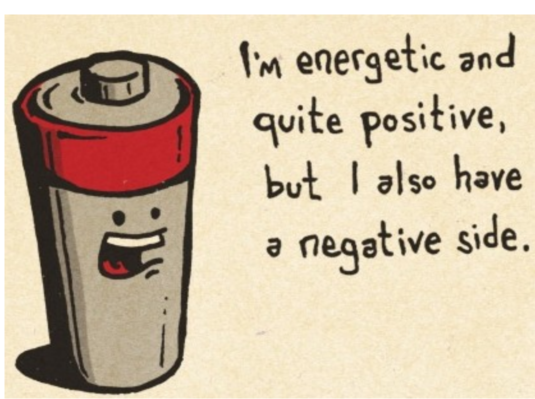


Description	Duracell branded consumer alkaline battery
Product Category	Electro-technical device
Use	Portable power source for electronic devices
Global sub-brands (Retail)	Coppertop, Plus, Quantum, Simply, Turbo, Ultra, Basic, TurboMax
Global sub-brands (B2B)	Procell, Industrial, OEM/OEA
Sizes	Major Cells: AA,AAA, C, D & 9V
Electro-technical System	Alkaline Manganese Dioxide
Electrode - Negative	Zinc (CAS # 7440-66-6)
Electrode - Positive	Manganese Dioxide (CAS # 1313-13-9)
Electrolyte	Alkali Metal Hydroxide (aqueous potassium hydroxide - CAS # 1310-58-3)
Materials of Construction - Can	Nickel Plated Steel
Ingestion/Small Parts Warning	Required for Small Cell or Battery (Sizes: AAA and Specialty Cells): Keep away from children. If swallowed, consult a physician immediately.
Normal Conditions of Use	Exposure to contents inside the sealed battery will not occur unless the battery leaks, is exposed to high temperatures, or is mechanically abused.
Note to Physician	A damaged battery will release concentrated and caustic potassium hydroxide.
First Aid - If swallowed	Do not induce vomiting. Seek medical attention immediately. USA CALLS ONLY - CALL 24-HOUR NATIONAL BATTERY INGESTION HOTLINE: (202) 625-3333 - COLLECT.
First Aid - Eye Contact	Flush with water for at least 15 minutes. Seek medical care if irritation persists.
First Aid - Skin Contact	Remove contaminated clothing. Wash skin with soap and water. Seek medical care if irritation persists.
Precautionary Statements	**CAUTION:** Batteries may explode or leak, and cause burn injury, if recharged, disposed of in fire, mixed with a different battery type, inserted backwards or disassembled. Replace all used batteries at the same time. Do not carry batteries loose in your pocket or purse. Do not remove the battery label. Keep small batteries (i.e., AAA) away from children. If swallowed, consult a physician at once.

Fire Hazard	Batteries may rupture or leak if involved in a fire.
Extinguishing Media	Use any extinguishing media appropriate for the surrounding area.
Fires Involving Large Quantities of Batteries	Large quantities of batteries involved in a fire will rupture and release caustic potassium hydroxide. Firefighters should wear self-contained breathing apparatus and protective clothing.

Handling Precautions	Avoid mechanical and electrical abuse. Do not short circuit or install incorrectly. Batteries may rupture or vent if disassembled, crushed, recharged or exposed to high temperatures. Install batteries in accordance with equipment instructions.
Storage Precautions	Store batteries in a dry place at normal room temperature. Refrigeration does not make them last longer.
Spills of Large Quantities of Loose Batteries (unpackaged)	Notify spill personnel of large spills. Irritating and flammable vapors may be released from leaking or ruptured batteries. Spread batteries apart to stop shorting. Eliminate all ignition sources. Evacuate area and allow vapors to dissipate. Clean-up personnel should wear appropriate PPE to avoid eye and skin contact and inhalation of vapors or fumes. Increase ventilation. Carefully collect batteries and place in appropriate container for disposal. Remove any spilled liquid with absorbent material and contain for disposal.
Collection & Proper Disposal	Dispose of used (or excess) batteries in compliance with federal, state/provincial and local regulations. Do not accumulate large quantities of used batteries for disposal as accumulations could cause batteries to short-circuit. Do not incinerate. In countries, such as Canada and the EU, where there are regulations for the collection and recycling of batteries, consumers should dispose of their used batteries into the collection network at municipal depots and retailers. They should not dispose of batteries with household trash.
USA EPA RCRA (40 CFR 261)	Classified as non-hazardous waste (not ignitable, corrosive, reactive or toxic). Federal Universal Waste Regulations (40 CFR 273) do not apply. State requirements may be more stringent than Federal.
California Universal Waste Rule (Cal. Code Regs. Title 22, Div. 4.5, Ch. 23)	California prohibits disposal of batteries as trash (including household trash).

Regulatory Status	Not regulated. Alkaline batteries (sometimes referred to as “Dry Cell” or “household” batteries) are not listed or regulated as dangerous goods under IATA Dangerous Goods Regulations, ICAO Technical Instructions, IMDG Code, UN Model Regulations, U.S. Hazardous Materials Regulations (49 CFR), and UNECE ADR.



Rechargeable batteries play an important role in our life and many daily chores would be unthinkable without the ability to recharge an empty battery. Points of interest are specific energy, years of service life, load characteristics, safety, price, self-discharge, environmental issues, maintenance requirements, and disposal.

Lead Acid — One of the oldest rechargeable battery systems; is rugged, forgiving if abused and economical in price; has a low specific energy and limited cycle life. Lead acid is used for wheelchairs, golf cars, personnel carriers, emergency lighting and uninterruptible power supply (UPS).

Nickel-cadmium (NiCd) — Mature and well understood; is used where long service life, high discharge current, extreme temperatures and economical price are of importance. Due to environmental concerns, NiCd is being replaced with other chemistries. Main applications are power tools, two-way radios, aircraft and UPS.

Nickel-metal-hydride (NiMH) — A practical replacement for NiCd; has higher specific energy with fewer toxic metals. NiMH is used for medical instruments, hybrid cars and industrial applications. NiMH is available in AA and AAA cells for consumer use.

Lithium-ion (Li?ion) — Most promising battery systems; is used for portable consumer products as well as electric powertrains for vehicles; is more expensive than nickel- and lead acid systems and needs protection circuit for safety.

The lithium-ion family is divided into three major battery types, so named by their cathode oxides, which are cobalt, manganese and phosphate. The characteristics of these Li-ion systems are as follows.

Lithium-ion-cobalt or *lithium-cobalt* (LiCoO2): Has high specific energy with moderate load capabilities and modest service life. Applications include cell phones, laptops, digital cameras and wearable products.

Lithium-ion-manganese or *lithium-manganese* (LiMn2O4): Is capable of high charge and discharge currents but has low specific energy and modest service life; used for power tools, medical instruments and electric powertrains.

Lithium-ion-phosphate or *lithium-phosphate* (LiFePO4): Is similar to lithium-manganese; nominal voltage is 3.3V/cell; offers long cycle life, has a good safe record but exhibits higher self-discharge than other Li-ion systems.

There are many other lithium-ion based batteries, some of which are described further on this website. Missing in the list is also the popular lithium-ion-polymer, or *Li-polymer*. While Li-ion systems get their name from their unique cathode materials, Li-polymer differs by having a distinct architecture. Nor is the rechargeable lithium-metal mentioned. This battery requires further development to control dendrite growth, which can compromise safety. Once solved, Li-metal will become an alternative battery choice with extraordinary high specific energy and good specific power.

Table 1 compares the characteristics of four commonly used rechargeable battery systems showing average performance ratings at time of publication.

Specifications	Lead Acid	NiCd	NiMH	Li-ion		
				Cobalt	Manganese	Phosphate
Specific energy density (Wh/kg)	30–50	45–80	60–120	150–190	100–135	90–120
Internal resistance[1] (mΩ)	<100 12V pack	100–200 6V pack	200–300 6V pack	150–300 7.2V	25–75[2] per cell	25–50[2] per cell
Cycle life[4] (80% discharge)	200–300	1000[3]	300–500[3]	500–1,000	500–1,000	1,000–2,000
Fast-charge time	8–16h	1h typical	2–4h	2–4h	1h or less	1h or less
Overcharge tolerance	High	Moderate	Low	Low. Cannot tolerate trickle charge		
Self-discharge/ month (room temp)	5%	20%[5]	30%[5]	<10%[6]		
Cell voltage (nominal)	2V	1.2V[7]	1.2V[7]	3.6V[8]	3.8V[8]	3.3V
Peak load current Best result	5C[9] 0.2C	20C 1C	5C 0.5C	>3C <1C	>30C <10C	>30C <10C
Operating temp.[10] (discharge only)	–20 to 60°C	–40 to 60°C	–20 to 60°C	–20 to 60°C		
Maintenance requirement	3–6 months[11]	30–60 days	60–90 days	Not required		
Safety requirements	Thermally stable	Thermally stable, fuse protection common		Protection circuit mandatory		
In use since	Late 1800s	1950	1990	1991	1996	2006
Toxicity	Very high	Very high	Low	Low		

Table 1: Characteristics of commonly used rechargeable batteries
The figures are based on average ratings of commercial batteries at time of publication; experimental batteries with above-average ratings are excluded.

1 Internal resistance of a battery pack varies with milliampere-hour (mAh) rating, wiring and number of cells. Protection circuit of lithium-ion adds about 100mW.
2 Based on 18650 cell size. Cell size and design determines internal resistance.
3 Cycle life is based on battery receiving regular maintenance.
4 Cycle life is based on the depth of discharge (DoD). Shallow DoD improves cycle life.
5 Self-discharge is highest immediately after charge. NiCd loses 10% in the first 24 hours, then declines to 10% every 30 days. High temperature increases self-discharge.
6 Internal protection circuits typically consume 3% of the stored energy per month.
7 The traditional voltage is 1.25V; 1.2V is more commonly used.
8 Low internal resistance reduces the voltage drop under load and Li-ion is often rated higher than 3.6V/cell. Cells marked 3.7V and 3.8V are fully compatible with 3.6V.
9 Capable of high current pulses; needs time to recuperate.
10 Applies to discharge only; charge temperature is more confined.
11 Maintenance may be in the form of equalizing or topping charge to prevent sulfation.

http://www.emeraldbatt.com/en/page/custom65-97/

Types of Batteries

NICKEL CADMIUM BATTERIES

The active components of a rechargeable NiCd battery in the charged state consist of nickel hydroxide (NiOOH) in the positive electrode and cadmium (Cd) in the negative electrode. For the electrolyte, potassium hydroxide (KOH) is normally used. Due to their low internal resistance and the very good current conducting properties, NiCd batteries can supply extremely high currents and can be recharged rapidly. These cells are capable of sustaining temperatures down to -20°C. The selection of the separator (nylon or polypropylene) and the electrolyte (KOH, LiOH, NaOH) influence the voltage conditions in the case of a high current discharge, the service life and the overcharging capability. In the case of misuse, a very high-pressure may arise quickly. For this reason, cells require a safety valve. NiCd cells generally offer a long service life thereby ensuring a high degree of economy.

NICKEL METAL HYDRIDE BATTERIES

The active components of a rechargeable NiMH battery in the charged state consist of nickel hydroxide (NiOOH) in the positive electrode and a hydrogen storing metal alloy (MH) in the negative electrode as well as a potassium hydroxide (KOH) electrolyte. Compared to rechargeable NiCd batteries, NiMH batteries have a higher energy density per volume and weight.

LITHIUM ION BATTERIES

The term lithium ion battery refers to a rechargeable battery where the negative electrode (anode) and positive electrode (cathode) materials serve as a host for the lithium ion (Li^+). Lithium ions move from the anode to the cathode during discharge and are intercalated into (inserted into voids in the crystallographic structure of) the cathode. The ions reverse direction during charging. Since lithium ions are intercalated into host materials during charge or discharge, there is no free lithium metal within a lithium-ion cell. In a lithium ion cell, alternating layers of anode and cathode are separated by a porous film (separator). An electrolyte composed of an organic solvent and dissolved lithium salt provides the media for lithium ion transport. For most commercial lithium ion cells, the voltage range is approximately 3.0 V (discharged, or 0 % state-of-charge, SOC) to 4.2 V (fully charged, or 100% SOC).

SMALL SEALED LEAD ACID BATTERIES

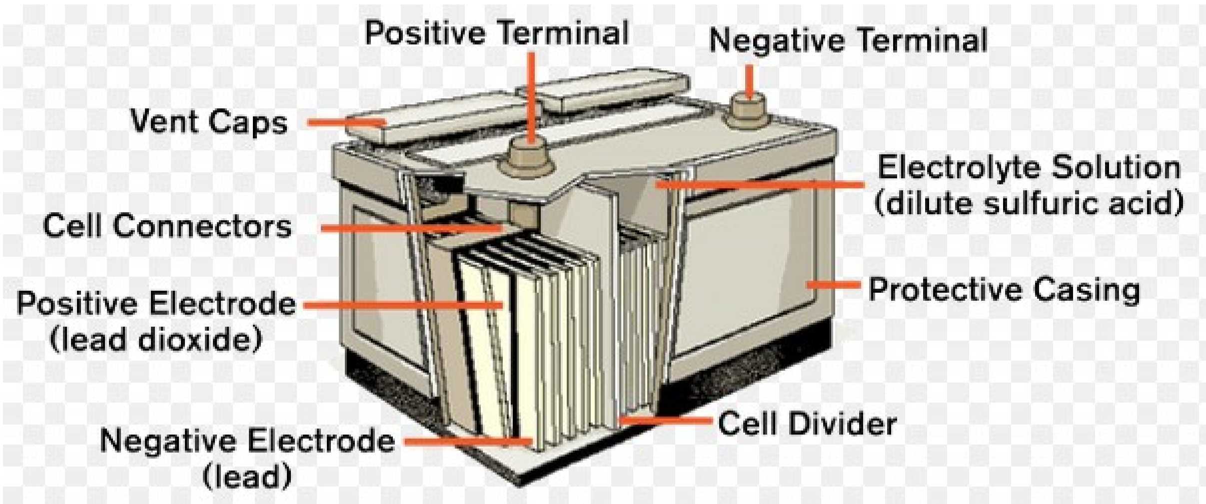
Rechargeable small sealed lead acid (SSLA) batteries, which are valve-regulated lead acid batteries, (VRLA batteries) do not require regular addition of water to the cells, and vent less gas than flooded (wet) lead-acid batteries. SSLA batteries are sometimes referred to as “maintenance free” batteries. The reduced venting is an advantage since they can be used in confined or poorly ventilated spaces.

There are two types of VRLA batteries,

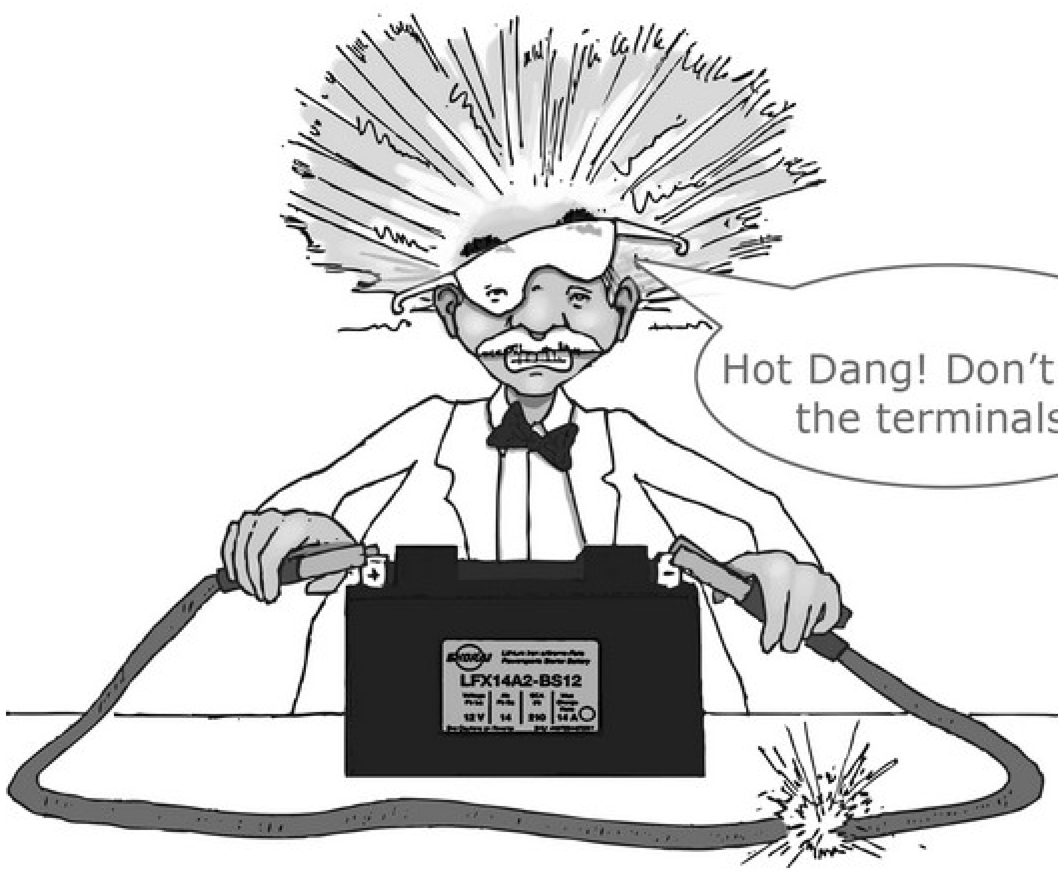
- Absorbed glass mat (AGM) battery
- Gel battery (“gel cell”)

An absorbed glass mat battery has the electrolyte absorbed in a fiber-glass mat separator. A gel cell has the electrolyte mixed with silica dust to form an immobilized gel.

SSLA batteries include a safety pressure relief valve. As opposed to flooded batteries, a SSLA battery is designed not to spill its electrolyte if it is inverted.



Lead Acid Battery



Lead Acid Battery Maintenance and Safety Protocol

Lead-acid batteries are physically large batteries that contain lead plates in a solution of acid to create electricity. They are a common power source for many applications; mostly cars, boats, standby power generators. Each year a state employee is injured during the operation and maintenance of these batteries. Nationally, 2300 people are injured each year using lead acid batteries. Acid burns to the face and eyes comprise about 50% of these injuries as these batteries can easily explode. The remaining injuries were mostly due to lifting or dropping batteries as they are quite heavy.

Lead-Acid battery Basics

- The electrolyte is a solution of sulfuric acid (35%) and water (65%). This solution can cause chemical burns to the skin and especially to the eyes.
- During normal operation, water is lost from a non-sealed (or flooded) battery due to evaporation.
- During charging, lead acid batteries produce hydrogen and oxygen gases (highly flammable/explosive) as electrolysis occurs.
- Many lead acid explosions are believed to occur when electrolytes are below the plates in the battery and thus, allowing space for hydrogen/oxygen to accumulate. When the battery is engaged, it may create a spark that ignites the accumulated gases and causes the battery to explode.

Standard Precautions

- Always store or recharge batteries in a well-ventilated area away from sparks or open flames
- Damaged lead acid batteries shall be kept in properly labeled acid-resistant secondary containment structures.
- Use only chargers that are designed for the battery being charged.
- Always keep lead acid battery vent caps securely in place.
- Do not store acid in hot locations or in direct sunlight.
- Pour concentrated acid SLOWLY into water; do not add water into acid.
- Use nonmetallic containers and funnels.
- If acid gets into your eyes, flush immediately with water for 15 minutes, and then promptly seek medical attention.
- If acid gets on your skin, rinse the affected area immediately with large amounts of water. Seek medical attention if the chemical burns appears to be a second degree or greater.

- Never over charge a lead acid battery and only replenish fluid with distilled water.
- Emergency wash stations should be located near lead-acid battery storage and charging areas.
- Prevent open flames, sparks or electric arcs in charging areas.
- Lead-acid storage and charging areas should be posted with “Flammable – No Smoking” signs.
- Neutralize spilled or splashed sulfuric acid solution with a baking soda solution, and rinse the spill area with clean water.

What to do when servicing batteries

- Keep metal tools and jewelry away from the battery.
- Inspect for defective cables, loose connections, corroded cable connectors or battery terminals, cracked cases or covers, loose hold-down clamps and deformed or loosed terminal posts.
- Replace worn or unserviceable parts.
- Check the state of charge of non-sealed and sealed batteries with an accurate digital voltmeter while the engine is not running, and lights and other electrically-powered equipment are turned off. Also check the electrolyte levels and specific gravity in each cell of non-sealed batteries.
- When checking the electrolyte liquid levels of the batteries use a rated flashlight that is intrinsically safe. In the event one is not available, Use a plastic/non-metallic flashlight, turn on the flash light prior to getting near the battery when checking cell levels and turn off the flash light when you are away from the batteries.
- Follow the battery manufacturer’s recommendations about when to recharge or replace batteries.
- Tighten cable clamp nuts with the proper size wrench. Avoid subjecting battery terminals to excessive twisting forces.
- Use a cable puller to remove a cable clamp from the battery terminal.
- Remove corrosion on the terminal posts, hold-down tray and hold-down parts.
- Use a tapered brush to clean battery terminals and the cable clamps.
- Wash and clean the battery, battery terminals, and case or tray with water. The corrosive acid can be neutralized by brushing on some baking soda (sodium bicarbonate) solution. If the solution does not bubble, the acid is probably neutralized. Rinse the battery with water to remove the baking soda solution.
- To prevent shocks, never touch or come in contact with both terminals at the same time. If baking soda solution is applied with a cloth, remember that these solutions can conduct electricity.
- When battery cables are removed, ensure that they are clearly marked “positive” and “negative” so that they are reconnected with the correct polarity.

- Use a battery carrier to lift a battery, or place hands at opposite corners. Remember, batteries can weigh 30 to 60 pounds, so practice safe lifting and carrying procedures to prevent back injuries.
- Use a self-leveling filler that automatically fills the battery to a predetermined level. Never fill battery cells about the level indicator.
- Do not squeeze the syringe so hard that the water splashes acid from the cell opening.

Required safety equipment in the battery recharging area

- Plumbed tepid water safety shower and eyewash station.
- Personal or Portable eyewash stations may be installed in the area immediate to the battery charging, if plumbed units cannot be installed. However, plumbed tepid water wash stations must be installed nearby to facilitate the required flushing of the eyes and skin.
- Non-vented safety goggles
- Face shield (considered secondary safety protection)
- Acid resistant gloves (neoprene is sufficient)
- Apron (If there is a potential to spill acid)
- Steel-toe boots or foot guards if the battery is lifted

Prior to starting the standby generator

1. Check the engine starting batteries to determine if the batteries are sealed or unsealed lead acid.
2. If the batteries are unsealed lead acid, check the electrolyte level in the battery before starting the generator.
3. If the electrolyte is low and the plates are exposed, do not start the generator. Add distilled water to the electrolyte to specified level in battery.
    - Wear gloves, safety glasses/goggles, face shield and apron.
    - Follow the instructions for adding water.
4. Wait at least an hour to allow time for the hydrogen gas generated in the battery to dissipate in the environment.

If acid gets into your eye(s), flush immediately with water for 15 minutes and then promptly seek medical attention.
If acid gets on your skin, rinse the affected area immediately with large amounts of water. Seek medical attention if the chemical burn appears to be second degree or greater.

5. Fire Fighting Measures

Suitable fire extinguishing agents:	CO_2 or dry powder extinguishing agents
Unsuitable fire extinguishing agents:	Water, if the battery voltage is above 120 V
Special protective equipment:	Protective goggles, respiratory protective equipment, acid protective equipment, acid-proof clothing in case of larger stationary battery plants or where larger quantities are stored.

6. Measures to be Taken in Case of Accidental Release

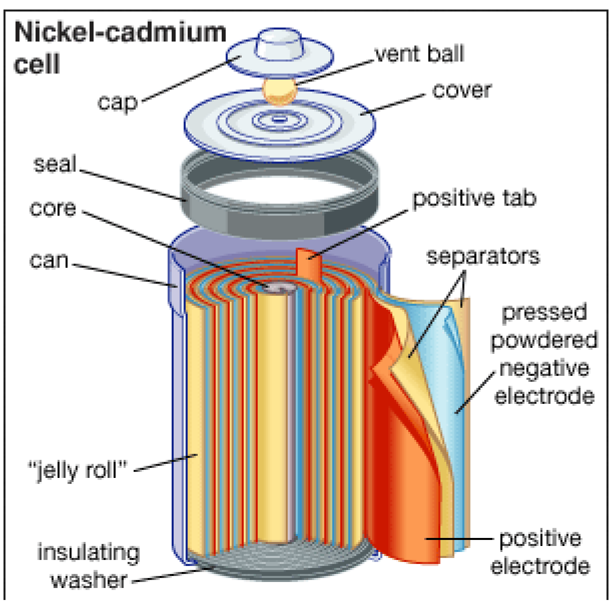
This information is of relevance only if the battery is broken and the contents are released.

In the case of spillage, use a bonding agent, such as sand, to absorb spilt acid; use lime / sodium carbonate for neutralisation; dispose of with due regard to the official local regulations; do not allow penetration into the sewage system, into earth or water bodies.

7. Handling and Storage

Store under roof in cool ambiance - charged lead-acid batteries do not freeze up to -50°C; prevent short circuits. Seek agreement with local water authorities in case of larger quantities of batteries to be stored. If batteries have to be stored, it is imperative that the instructions for use are observed.

Nickel Cadmium Batteries



Nickel-Cadmium Batteries

A number of secondary, i.e. rechargeable, alkaline batteries or cells incorporate cadmium as an active electrode material. The most important and best known of these is the nickel-cadmium cell which is based on the reversible electrochemical reactions of cadmium and nickel in a potassium hydroxide (alkaline) electrolyte. At the negative electrode (cathode) the cadmium oxidises to cadmium hydroxide on discharge whilst the hydrated nickel compounds at the positive electrode (anode) are reduced to nickel hydroxide, thus:

2Ni(OH)2+Cd(OH)2 <-- charge/discharge --> 2NiO OH + Cd + 2H20

The potassium hydroxide electrolyte takes no part in the charge-discharge reactions and acts only as a charge carrier. Lithium hydroxide may be added to the electrolyte to increase the life of the positive electrode. The reaction produces a nominal usable electromotive force of 1.2 volts per cell.

A number of types of cell construction are possible. These variations in cell construction lie mostly in the nature of electrode support utilized. For the positive electrode three principal types are recognized - pocket plate, sintered plate and fiber plates. An electrode support is necessary because the active material (nickel hydroxide) is usually in powder form and held in pocket plates or mixed with gel or paste and placed in sintered or fiber electrodes. Also, graphite or iron oxide needs to be added to improve the conductivity of both nickel and cadmium hydroxide.

Negative electrode designs make use of an even broader range of materials including pocket plates, sintered nickel powder, fiber, foam and plastic bonded supports. It is the physical stability of the active material (cadmium hydroxide) in the negative electrode that permits such a wide variety of support materials. Nickel hydroxide, however, swells appreciably during charge and discharge, straining the support and restricting the choice of support type at the positive electrode. In all cell construction types a separator is placed between the two electrodes to prevent short circuits.

Nickel-cadmium batteries are characterized by their resistance to electrical abuse, high cycle lives, reliability and versatility and have found a wide range of application. The several types of cell construction are manufactured in a wide range of size, capacity and shape and the choice of a particular battery will depend upon the application and its current load requirements.

These applications are principally of two types industrial and portable batteries.

(a) Industrial nickel-cadmium batteries

Nickel-cadmium batteries for industrial uses are of the vented (or open) or semi-sealed type and may be of pocket plate, sintered plate or fiber structured construction. Applications for industrial batteries include railway uses such as locomotive starting, emergency braking, coach lighting and air conditioning, trackside power for signaling and warning lights and others. Other uses include standby power for alarm systems, emergency lighting, military communications, solar energy storage, navigation equipment, military equipment, hospital operating theaters and many others. Semi-sealed industrial batteries are used in aeronautical applications where they are used to start engines and also to provide stand-by power for aircraft systems when the principal power source fails. After long periods of operation most vented or semi-sealed cells may require electrolyte maintenance by topping up with distilled water.

(b) Portable nickel-cadmium batteries

Nickel-cadmium batteries for portable use are of the sealed type and are generally of sintered plate construction. They may be of cylindrical , button or prismatic design. Sealed nickel-cadmium batteries are in strong demand for use in consumer electronic equipment such as cellular telephones, portable tools, toys, camcorders and other domestic cordless appliances. They are also used for memory back-up in computing equipment, military and civil communications, emergency lighting and many other similar applications. Sealed cells require no maintenance and may be recharged up to 2000 times.

http://www.cadmium.org/pg_n.php?id_menu=14

NiCad Battery Charging Basics

NiCad (NiCd, Nickel Cadmium) Battery Charging

Nickel Battery Charging Basics

NiCad and NiMH batteries are amongst the hardest batteries to charge. Whereas with lithium ion and lead acid batteries you can control overcharge by just setting a maximum charge voltage, the nickel based batteries don't have a "float charge" voltage. So the charging is based on forcing current through the battery. The voltage to do this is not fixed in stone like it is for the other batteries.

This makes these cells and batteries especially difficult to charge in parallel. This is because you can't be sure that each cell or pack is the same impedance (or resistance), and so some will take more current than others *even when they are full.* This means that you need to use a separate charging circuit for each string in a parallel pack, or balance the current in some other way, for example by using resistors of such a resistance that it will dominate the current control.

The coulometric charging efficiency of nickel cadmium is about 83% for a fast (C/1 to C/0.24) charge, and 63% for a C/5 charge. This means that at C/1 you must put in 120 amp hours in for every 100 amp hours you get out. The slower you charge the worse this gets. At C/10 it is 55%, at C/20 it can get less than 50%. (These numbers are just to give you an idea, battery manufacturers differ).

When the charge is complete oxygen starts being generated at the nickel electrode. This oxygen diffuses through the separator and reacts with the cadmium electrode to form cadmium hydroxide. This causes a lowering of the cell voltage which can be used to detect the end of charge. This so-called minus delta V/ delta t bump that is indicative of end-of-charge is much less pronounced in NiMH than NiCad, and it is very temperature dependent.

As the battery reaches end-of-charge oxygen starts to form at the electrodes, and be recombined at the catalyst. This new chemical reaction creates heat, which can be easily measured with a thermistor.. This is the safest way to detect end-of-charge during a fast charge.

Nickel cadmium battery chargers should cut the charge off when the temperature exceeds the maximum charging temperature, typically 45 degrees C for a controlled fast charge, and 50 degrees C for an overnight or fast charge.

Overnight Battery Charging

The cheapest way to charge a nickel cadmium battery is to charge at C/10 (10% of the rated capacity per hour) for 16 hours.. So a 100 mAH battery would be charged at 10 mA for 16 hours. This method does not require an end-of-charge sensor and ensures a full charge. Cells can be charged at this rate no matter what the initial state of charge is. The minimum voltage you need to get a full charge varies with temperature--at least 1.41 volts per cell at 20 degrees C. The best charging practice is to use a timer to prevent overcharging to continue past 16 hours. An example of this kind of charger is shown at http://www.powerstream.com/NiMHWM.htm . This charger uses a microprocessor to report the state of charge via an LED as well as performing the timing function.

Faster Charging

Some nickel cadmium cells are designed to be "quick chargeable." This is just a timed charge at C/3 for 5 hours, or C/5 for 8 hours. This is risky because the battery should be fully discharged before charging. If the battery still has 90% of its capacity when the timer starts you would have a good chance of venting the battery. One way to ensure this doesn't happen is to have the charger automatically discharge the battery to 1 volt per cell, then turn the charger on for 5 hours. The advantage of this method is to eliminate any chance of battery memory. PowerStream does not currently have such a charger, but the microprocessor board used in the C/10 charger http://www.powerstream.com/NiMHWM.htm could easily be modified to do the discharge. A power dissipating package would be needed in order to dissipate the energy from a partially charged battery in a reasonable amount of time.

Fastest Charging

If a temperature or voltage monitor is used NiCad batteries can be charged at rates up to 1C (in other words 100% of the battery capacity in amp-hours for 1.5 hours). The PowerStream battery charge controller shown in http://www.powerstream.com/product3.htm does this, as does the battery management board shown in http://www.powerstream.com/product5.htm.

The termination can be done with minus delta V, when the battery voltages drops -10 to -20 mV per cell. To terminate the charge on temperature requires a temperature slope measurement.

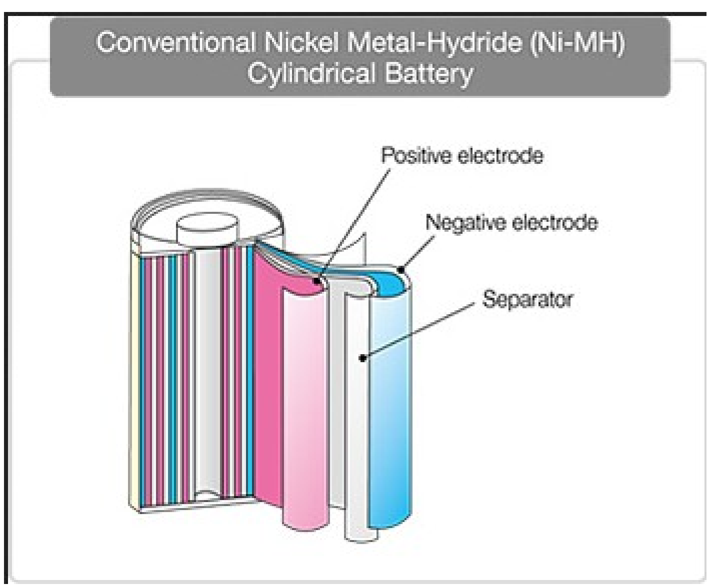
This board also has the ability to sense voltage and current for more sophisticated algorithms required for ultra-fast charging. These algorithms require constant monitoring of the voltage, temperature, and sometimes pressure, to actively determine the amount of current a battery can take without damage. This is sometimes called a smart charge, or a controlled fast charge.

A cheaper version of the fast charger can be made by just monitoring absolute temperature. The charge rate is set at C/2 until 45 degrees C is reached, then switched over to a C/10 charge to complete the charge.

Trickle Charging Nickel Batteries

In a standby mode you might want to keep a nickel cadmium battery topped up without damaging the battery. This can be done safely at a current of between 0.05 C and .06 C. The voltage required for this is dependent on temperature, so be sure to regulate the current in the charger.

Nickel Metal Hydride Batteries



NiMH Charging

Basics

NiCad and NiMH batteries are amongst the hardest batteries to charge accurately. Whereas with lithium ion and lead acid batteries you can control overcharge by just setting a maximum charge voltage, the nickel based batteries don't have a "float charge" voltage. So the charging is based on forcing current through the battery. The voltage to do this is not fixed in stone like it is for the other batteries.

Parallel Charging: This makes these cells and batteries difficult to charge in parallel. This is because you can't be sure that each cell or pack is the same impedance (or resistance), and so some will take more current than others *even when they are full.* This means that you need to use a separate charging circuit for each string in a parallel pack, or balance the current in some other way, for example by using resistors of such a resistance that it will dominate the current control.

The coulometric charging efficiency of nickel metal hydride batteries is typically 66%, meaning that you must put 150 amp hours into the battery for every 100 amp hours you get out. The faster you charge the worse this gets.

The minus delta V bump that is indicative of end-of-charge is much less pronounced in NiMH than NiCad, and it is very temperature dependent. To make matters worse, new NiMH batteries can exhibit bumps in the curve early in the cycle, particularly when cold. Also, NiMH are sensitive to damage on overcharge when the charge rate is over C/10. Since the delta V bump is not always easy to see, slight overcharge is probable. For this reason PowerStream does not recommend using simple minus delta V as a termination criterion for nickel metal hydride batteries.

However, modern algorithms have been developed to enable accurate charging without using a thermistor. These chargers are similar to the -delta V chargers, but have special measurement techniques to detect a full charge, usually involving some kind of pulse cycle where the voltage is measured during the pulse and between pulses. For multi cell packs, if the cells are not all at the same state of charge, and if they are not balanced in capacity, the cells may fill up one at a time, blurring out the end-of-charge signal. In order to balance the cells it may take several charge-discharge cycles. Luckily, NiMH does not mind being overcharged at C/10 or less, which allows the charger to balance the cells during the trickle charge.

As the battery reaches end-of-charge oxygen starts to form at the electrodes, and be recombined at the catalyst. This new chemical reaction creates heat, which can be easily measured with a thermistor. This is the safest way to detect end-of-charge during a fast charge.

Overnight Charging

The cheapest way to charge a nickel metal hydride battery is to charge at C/10 or below (10% of the rated capacity per hour). So a 100 mAH battery would be charged at 10 mA for 15 hours. This method does not require an end-of-charge sensor and ensures a full charge. Modern cells have an oxygen recycling catalyst which prevents damage to the battery on overcharge, but this recycling cannot keep up if the charge rate is over C/10. The minimum voltage you need to get a full charge varies with temperature--at least 1.41 volts per cell at 20 degrees C. Even though continued charging at C/10 does not cause venting, it does warm the battery slightly. To preserve battery life the best practice is to use a timer to prevent overcharging to continue past 13 to 15 hours. Examples of this kind of charger are shown at http://www.powerstream.com/NiMHWM.htm . This charger uses a microprocessor to report the state of charge via an LED as well as performing the timing function.

Faster Charging

Using a timer it is possible to charge at C/3.33 for 5 hours. This is a little risky, since the battery should be fully discharged before charging. If the battery still has 90% of its capacity when the timer starts you would have a good chance of venting the battery. One way to ensure this doesn't happen is to have the charger automatically discharge the battery to 1 volt per cell, then turn the charger on for 5 hours. The advantage of this method is to eliminate any chance of battery memory. PowerStream does not currently have such a charger, but the microprocessor board used in the C/10 charger http://www.powerstream.com/NiMHWM.htm could easily be modified to do the discharge. A power dissipating package would be needed in order to dissipate the energy from a partially charged battery in a reasonable amount of time. Another example of a 3 hour charger is http://wwww.powerstream.com/9vnmh.htm . This is a very inexpensive microprocessor based 9 volt "transistor radio" battery charger that that drops to low current when the battery voltage indicates a full charge.

Fastest Charging

If a temperature monitor is used NiMH batteries can be charged at rates up to 1C (in other words 100% of the battery capacity in amp-hours for 1.5 hours). The PowerStream battery charge controller shown in http://www.powerstream.com/product3.htm does this, as does the battery management board shown in http://www.powerstream.com/product5.htm.

This board also has the ability to sense voltage and current for more sophisticated algorithms.

When terminating on temperature rise the dT/dt value should be set at 1 to 2 degrees C per minute.

Trickle Charging

In a standby mode you might want to keep a nickel metal hydride battery topped up without damaging the battery. This can be done safely at a current of between 0.03 C and .05 C. The voltage required for this is dependent on temperature, so be sure to regulate the current in the charger.

dT/dt versus -dV/dt

These two termination methods work well for NiCads, and are both applied to NiMH as well. dT/dt measures the temperature rise at the end of charge. After the battery is fully charged it starts new chemical reactions in order to absorb the unneeded current. In nickel hydroxide style batteries this consists in generating and recombining oxygen. This process heats the battery. The sudden increase in temperature rise can be used to terminate the charge.

Another effect of the oxygen generation/recombination cycle is to depress the voltage of the battery slightly. If you can detect this voltage depression you can use this signal to terminate the charge. Of course, -dV/dt is the easiest because it doesn't require a temperature sensor. The best method for NiMH is the dT/dt method. There are two main reasons. With the NiMH battery the voltage depression is smaller, and harder to detect than with the NiCad battery.

This almost always ensures an overcharge, which will limit the total number of charge/discharge cycles before battery failure. Second, a new NiMH battery has false peaks early in the charge cycle, and so the charger will terminate too soon.

There are new algorithms that use microprocessor control to use the -dV signal to detect the end of charge. These can work very well and several of our chargers use this technique, which involves pulsing the charger on and off to do the voltage measurements. This technique seems to be sensitive to imbalance in the capacity of the cells. The dT/dt is still more reliable, especially for large packs, but in cases when only two wires are available solutions are now available.

The Ultimate Charger

Sometimes the most important issue is the lifetime of the batteries or the total lifetime cost of the system. In this case PowerStream is in a good position to offer the ultimate charger because of our wide experience in microprocessor controlled battery chargers and power supplies. Specs for the ultimate (fantasy) charger are:

1. Soft start. If the temperature is above 40 degrees C or below zero degrees C start with a C/10 charge. If the discharged battery voltage is less than 1.0 Volts/cell start with a C/10 charge. If the discharged battery voltage is above 1.29 V/cell start with a C/10 charge.

2. Option: if the discharged battery voltage is above 1.0 Volts/cell, discharge the battery to 1.0 V/cell then proceed to rapid charge.

3. Rapid charge at 1 C until the temperature reaches 45 degrees C, or the dT/dt indicates full charge.

4. After terminating the fast charge, slow charge at C/10 for 4 hours to ensure a full charge.

5. If the voltage climbs to 1.78 V/cell without otherwise terminating, terminate.

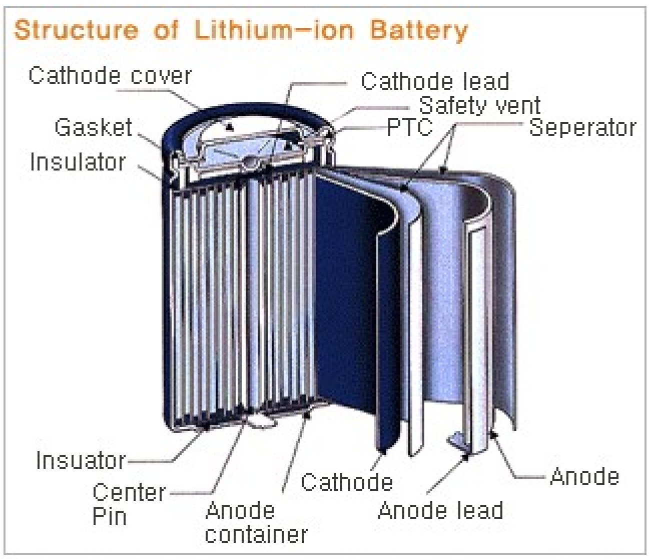
6. If the time on fast charge exceeds 1.5 hours without otherwise terminating, terminate the fast charge.

7. If the battery never reaches a condition where the fast charge starts time out the slow charge after 15 hours.

8. Fuel gauge, communication to the device being powered, LED indicators all possible.

http://www.powerstream.com/NiMH.htm

Lithium Ion Battery



Safety Hazards of Batteries

Battery technology is at the heart of much of our technological revolution. One of the most prevalent rechargeable batteries in use today is the Lithium-ion battery. Cell phones, laptop computers, GPS systems, iPods, and even cars are now using lithium-ion rechargeable battery technology. In fact, you probably have a lithium-ion battery in your pocket or purse right now!
Although lithium-ion batteries are very common there are some inherent dangers when using **ANY** battery. Lithium cells are like any other technology – if they are abused and not used for their intended purpose catastrophic results may occur, such as: first-, second-, and third-degree burns, respiratory problems, fires, explosions, and even death. Please handle the lithium-ion batteries with care and respect.

User Safety Precautions

Short-Circuiting

• **When the battery is not in use, you MUST disconnect the battery from the battery connector. When the battery is connected to the battery connector, do not leave unattended since the two wires with the alligator clips can touch which will heat up the battery. Short circuiting will damage the battery and generate heat that can cause burns.**

• Don't leave the battery in the charger once it is fully charged. The battery charger will flash on and off with a red indicator light every 20 seconds when the battery is fully charged. Overcharging the batteries will not increase the performance and could lead to damage.

Disassembly

• Never disassemble a battery as the materials inside may be toxic and may damage skin and clothes.

• DO NOT place a battery in fire; this may cause the battery to rupture. The electrolyte is very flammable and if an ignition source exists, then fire and even an explosion could result.

• NEVER place batteries in water, as this may cause the battery to rupture and release poisonous gasses. Furthermore, when the electrolyte is combined with water, there is the potential for hydrofluoric acid to form – an extremely toxic and corrosive substance. To learn more about hydrofluoric acid, visit the following link to the Centers for Disease Control's website:
http://www.bt.cdc.gov/agent/hydrofluoricacid/basics/facts.asp

Soldering

• Never solder anything directly to a battery. This can destroy the safety features of the battery by damaging the safety vent inside the cap.

Charging

• Never charge with an unspecified charger or specified charger that has been modified. This can cause breakdown of the battery or swelling and rupturing.

• Never attempt to charge a battery which has been physically damaged.

• Avoid designing airtight battery compartments. In some cases, gases (oxygen, hydrogen) may be given off, and there is a danger of a battery bursting or rupturing if ignited by sparks.

• Do not use a battery in an appliance or purpose for which it was not intended.

Safety Procedures

• If the foil packaging on the battery does break, vent the room and leave area.

• If a fire starts, call the fire department immediately. The only extinguisher that will work on a Lithium-ion Battery fire is a Class D Fire Extinguisher or Dry Sand or Dry Table Salt.

Battery Disposal

Lithium-ion batteries are found in many electronics like laptops, digital cameras, power tools, and cordless phones. These batteries are very popular because they can be recharged and because they are able to supply power for a long period of time. However, even lithium-ion batteries reach a point where they can no longer hold a charge and need to be disposed of. When this time comes, it is important to know how to recycle the battery, and not simply put it in a trash can. Determine your states recycling policy.

Health Concerns with Batteries

Become familiar with the dos and don’ts when handling batteries.

Batteries are safe, but precaution applies when touching damaged cells and when handling lead acid systems that have access to lead and sulfuric acid. Several countries label lead acid as hazardous material, and rightly so. Let’s look at the health hazards if not properly handled.

Lead is a toxic metal that can enter the body by inhalation of lead dust or ingestion when touching the mouth with lead-contaminated hands. If leaked onto the ground, the acid and lead particulates contaminate the soil and become airborne when dry. Children and fetuses of pregnant women are most vulnerable to lead exposure because their bodies are developing. Excessive levels of lead can affect a child’s growth, cause brain damage, harm kidneys, impair hearing and induce behavioral problems. In adults, lead can cause memory loss and lower the ability to concentrate, as well as harm the reproductive system. Lead is also known to cause high blood pressure, nerve disorders, and muscle and joint pain. Researchers believe that Ludwig van Beethoven became ill and died because of lead poisoning.

The sulfuric acid in a lead acid battery is highly corrosive and is potentially more harmful than acids used in other battery systems. Eye contact can cause permanent blindness; swallowing damages internal organs that can lead to death.

First aid treatment calls for flushing the skin for 10 to 15 minutes with large amounts of water to cool the affected tissues and to prevent secondary damage. Immediately remove contaminated clothing and thoroughly wash the underlying skin. Always wear protective equipment when handling the sulfuric acid.

Cadmium, which is used in nickel-cadmium batteries, is considered more harmful than lead if ingested. Workers at NiCd manufacturing plants in Japan have been experiencing health problems from prolonged exposure to the metal, and governments have banned disposal of nickel-cadmium batteries in landfills. The soft, whitish metal that occurs naturally in the soil can damage kidneys. Cadmium can be absorbed through the skin by touching a spilled battery. Since most NiCd batteries are sealed, there are no health risks in handling in-tact cells. The caution applies when working with an open battery.

Nickel-metal-hydride is considered non-toxic and the only concern is the electrolyte. Although toxic to plants, nickel is not harmful to humans. Lithium-ion is similarly benign – the battery contains little toxic material. Nevertheless, caution is required when working with a damaged battery. When handling a spilled battery, do not touch your mouth, nose and eyes, and wash your hands thoroughly.

Keep small batteries out of children's reach. Children younger than four are most likely to swallow batteries, and the most common types ingested are button cells. Each year in the United States alone, more than 2,800 kids are treated in emergency rooms after swallowing button batteries. According to a 2015 report, serious injuries and deaths in swallowing batteries have increased nine-fold in the last decade.

The battery often gets stuck in the esophagus (the tube that passes food). Water or saliva creates an electrical current that can trigger a chemical reaction producing hydroxide, a caustic ion that causes serious burns the surrounding tissue. Doctors often misdiagnose the symptoms, which can show as fever, vomiting, poor appetite and weariness. Batteries that make it through the esophagus often move through the digestive tract with little or no lasting damage. The concern of a parent is not only to choose safe toys, but also to keep small batteries away from young children.

Safety Tips

- Keep button batteries out of sight and reach of children. Remote controls, singing greeting cards, watches, hearing aids, thermometers, toys and electric keys may contain these batteries.

- Keep loose batteries locked away to prevent access by small children.
- Share the danger of swallowing button batteries with caregivers, friends, family members and baby sitters.
- If you suspect your child has ingested a battery, go to the hospital immediately. Wait for a medical assessment before allowing the child to eat and drink.

Charging batteries in living quarters should be safe. This also applies to lead acid. Ventilate the dwellings regularly as you would a kitchen when cooking. Lead acid produces some hydrogen gas but the amount is minimal when charged correctly. Hydrogen gas becomes explosive at a concentration of 4 percent. This would only be achieved if large lead acid batteries were charged in a sealed room.

Over-charging a lead acid battery can produce hydrogen-sulfide. The gas is colorless, very poisonous, flammable and has the odor of rotten eggs. Hydrogen sulfate also occurs naturally during the breakdown of organic matter in swamps and sewers; it is also present in volcanic gases, natural gas, and some well waters. Being heavier than air, the gas accumulates at the bottom of poorly ventilated spaces. Although noticeable at first, the sense of smell deadens with time and potential victims may be unaware of its presence.

As a simple guideline, hydrogen sulfide becomes harmful to human life if the odor is noticeable. Turn off the charger, vent the facility and stay outside until the odor disappears. (To learn about potential hazards when incorrectly charging Li-ion, see Lithium Safety Concerns.)

Caution:

> When charging an SLA with over-voltage, current limiting must be applied to protect the battery. Always set the current limit to the lowest practical setting and observe the battery voltage and temperature during charge.
>
> In case of rupture, leaking electrolyte or any other cause of exposure to the electrolyte, flush with water immediately. If eye exposure occurs, flush with water for 15 minutes and consult a physician immediately.
>
> Wear approved gloves when touching electrolyte, lead and cadmium. On exposure to skin, flush with water immediately.

Safety Concerns with Li-ion

Learn what causes Li-ion to fail and what to do in case of fire.

Modern batteries contain highly reactive chemicals that will react at elevated temperature by default. The objective is to operate in a stable environmental bandwidth.

Safety is a sensitive issue that gets much media and legal attention, especially with Li-ion batteries. Any energy storage device carries a risk, and in the 1800s steam engines exploded and people got hurt. Carrying highly flammable gasoline in cars was a hot topic in the early 1900s. Battery makers are obligated to meet safety requirements, but less reputable firms may cheat — it's "buyers be beware!" Most OEMs use only Li-ion batteries that comply with one or several safety standards. [BU-207 Safety Concerns with Li-ion, UL1642]

Lithium-ion is safe but with millions of consumers using batteries, failures are bound to happen. In 2006, a one-in-200,000 breakdown triggered a recall of almost six million lithium-ion packs. Sony, the maker of the lithium-ion cells in question, points out that on rare occasions microscopic metal particles may come into contact with other parts of the battery cell, leading to a short circuit within the cell.

Battery manufacturers strive to minimize the presence of such particles; however, complex assembly techniques make the elimination of all metallic dust a challenge. Cells with ultra-thin separators of 24µm or less are more susceptible to impurities than the older designs with lower Ah ratings. Whereas the 1,350mAh cell in the 18650 package could tolerate the nail penetration test, the high-density 3,400mAh can ignite when performing the same test. New safety standards are more relevant to how batteries are used and the UL1642 Underwriters Laboratories (UL) test no longer mandates nail penetration for safety acceptance of lithium-based batteries.

Li-ion using conventional metal oxides is nearing its theoretical limit on specific energy. Rather than optimizing capacity, battery makers are improving manufacturing methods to enhance safety and increase the calendar life. The real problem lies in rare occasions when an electrical short develops inside the cell. The external protection peripherals in such a case are ineffective to stop the thermal runaway when in progress. The batteries recalled in 2006 had passed the UL safety requirements — yet they failed under normal use.

Let's examine the inner workings of the cell closer. A mild short will only cause elevated self-discharge and the heat buildup is minimal because the discharging power is very low. If enough microscopic metallic particles converge on one spot, a sizable current begins to flow between the electrodes of the cell and the spot heats up and weakens. As a small water leak in a faulty hydro dam can develop to a torrent and take a structure down, so also can heat buildup damage the insulation layer in a cell and cause an electrical short. The temperature can quickly reach 500°C (932°F), at which point the cell catches fire or it explodes. This thermal runaway that occurs is known as "venting with flame." "Rapid disassembly" is the preferred term by the battery industry.

Uneven separators can also trigger cell failure. Poor conductivity due to dry area increases the resistance, which can generate local heat spots that weaken the integrity of the separator. Heat is always an enemy of the battery.

What to do when a battery overheats . . .

If the battery overheats, hisses or bulges, immediately move the device away from flammable materials and place it to a non-combustible surface. If at all possible, put a disintegrating device outdoors and let it burn out. If the fire occurs in an airplane, the FAA instructs flight attendants not to use fire extinguishers but the use of water or pop soda. Water cools the adjacent material and prevents the fire from spreading. Many research laboratories and factories also use water to put out battery fires. Allow good ventilation while the battery burns itself out. Li-ion contains no lithium metal and does not react with water (lithium metal batteries requires different extinguishing methods).

During a thermal runaway, the high heat of the failing cell may propagate to the next cells, causing them to become thermally unstable also. A chain reaction can occur in which each cell disintegrates on its own timetable. A pack can thus be destroyed in a few seconds or over several hours as each cell is being consumed. To increase safety, packs should include dividers to protect the failing cell from spreading to the neighboring one. Figure 1 shows a laptop that was damaged by a faulty Li-ion battery.

Figure 1: Suspected Li-ion battery destroys laptop

The owner says the laptop popped, hissed, sizzled and began filling the room with smoke.

Courtesy of Shmuel De-Leon

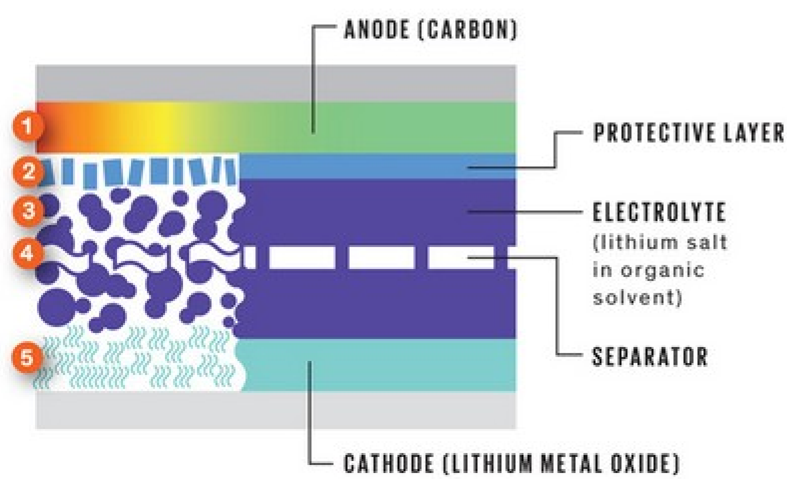
The gas released by venting of a Li-ion cell as part of pressure buildup is mainly carbon dioxide (CO_2). Other gases that form through abusive heating are vaporized electrolyte consisting of ethylene and/or propylene. Burning gases include combustion products of the organic solvents.

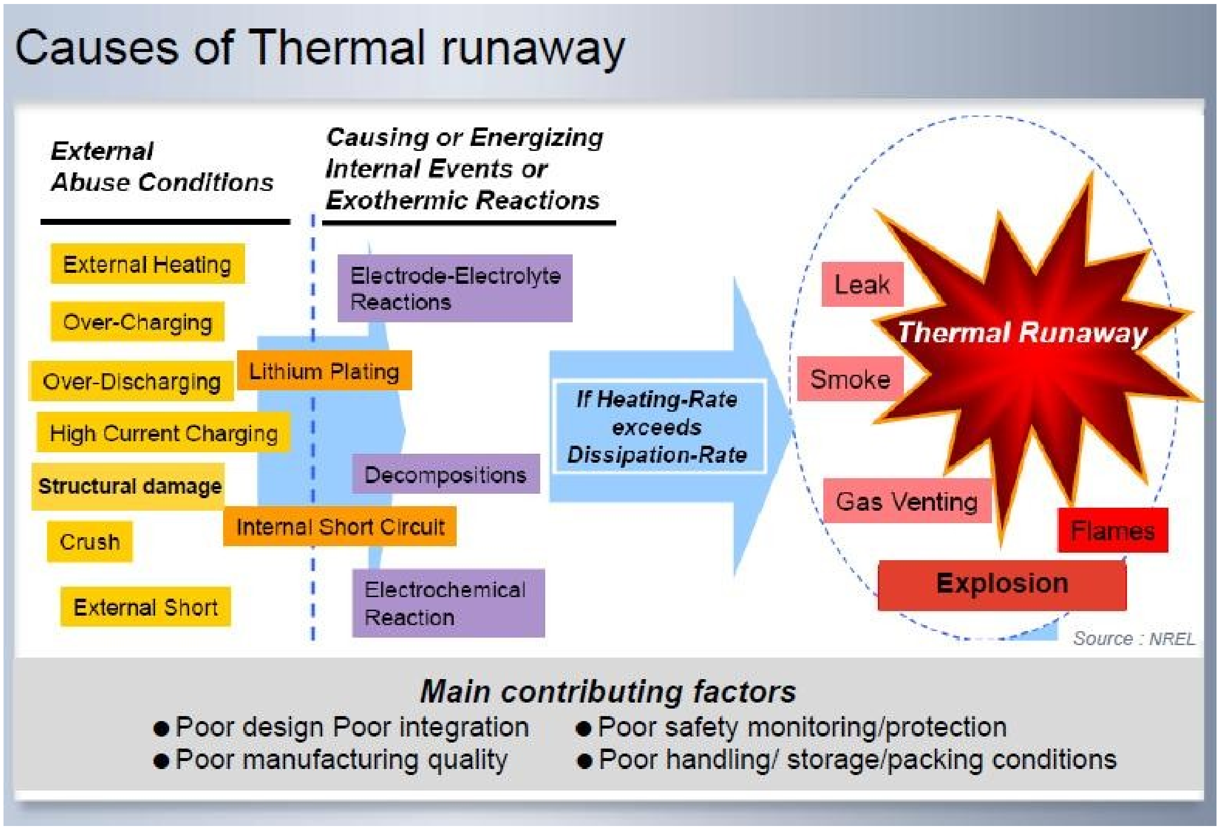
While lithium-based batteries are heavily scrutinized for safety, nickel- and lead-based batteries also cause fires and are being recalled. The reasons are faulty separators resulting from aging, rough handling, excessive vibration and high-temperature. Lithium-ion batteries have become very safe and heat-related failures occur rarely under correct use.

- Use a foam extinguisher, CO_2, dry chemical, powdered graphite, copper powder or soda (sodium carbonate) to extinguish a lithium-ion fire. **Only pour water to prevent the fire from spreading as water interacts with lithium.**
- If the fire of a burning lithium-ion battery cannot be extinguished, allow the pack to burn out on its own in a controlled and safe way.
- Watch out for cell propagation as each cell can be consumed on its own time table. Place a seemingly burned-out pack outside for a time.

Thermal Runaway in a Lithium-Ion Battery

1. Heating starts.
2. Protective layer breaks down.
3. Electrolyte breaks down into flammable gases.
4. Separator melts, possibly causing a short circuit.
5. Cathode breaks down, generating oxygen.





Batteries are everywhere. Let's all learn how to use them, charge them, and care for them properly.