Batteries for Amateur Radio

RMHAM University

01-09-2021

KI0KN

Common types

- Alkaline (Typical AA or 9 volt type)
- NiCd/NiMh
- Lithium
- Lead Acid
  - Flooded/SLA/AGM/Gel

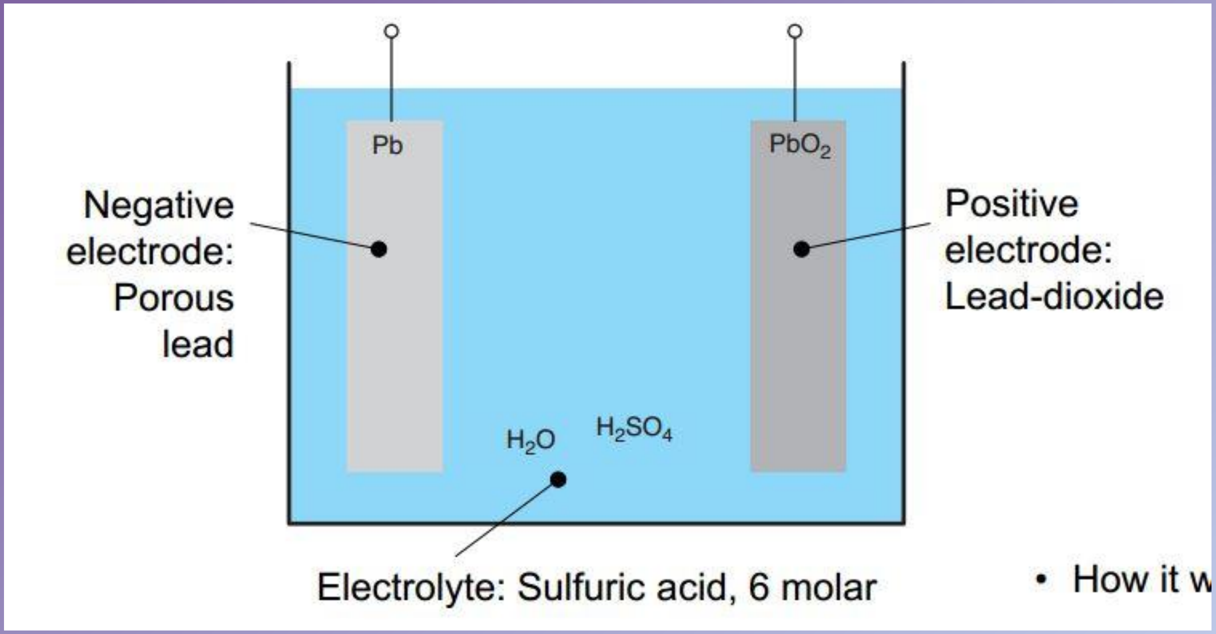
Lead Acid Batteries

- Types
  - Flooded (Typical car battery)
    - Starting
    - Deep cycle
  - AGM (Absorbed Glass Mat)
  - Gel cell

Construction

- Battery made of (6) 2.0 volt cells
- Positive terminal Lead Dioxide
- Negative terminal Porous Lead
- Electrolyte is ~6 molar Sulfuric acid and water

Construction



Construction

- Starting battery
  - Many more plates, much thinner
    - Provides much more surface area for more current
  - Easily damaged by heavy discharge
    - Plates warp
  - Delivers very high current for very short period

Construction

- Deep cycle
  - Fewer plates, much thicker
    - Less surface area means less current
  - Resists warping, can be discharged much farther
  - Delivers lower current for longer period

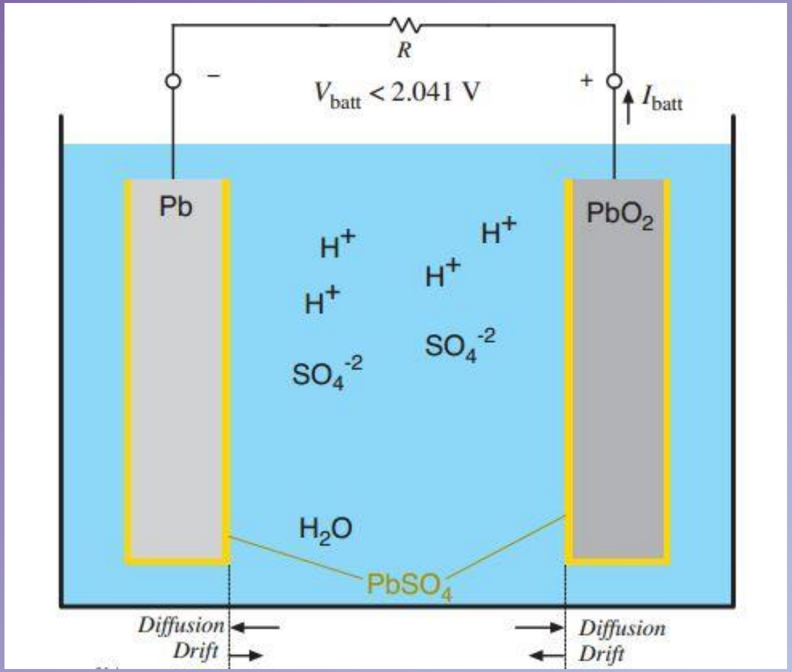
The discharge / charge process

- A little bit of chemistry
- Changes that happen inside
  - Why these are important to understand!

Discharge

- Connection of an electrical load allows electrons to flow from negative to positive terminals
- This reduces the charge and the voltages at the electrodes
- The chemical reactions are able to proceed, generating new electrons and generating the power that is converted to electrical form to drive the external electrical load
- As the battery is discharged, the electrodes become coated with lead sulfate and the acid electrolyte becomes weaker

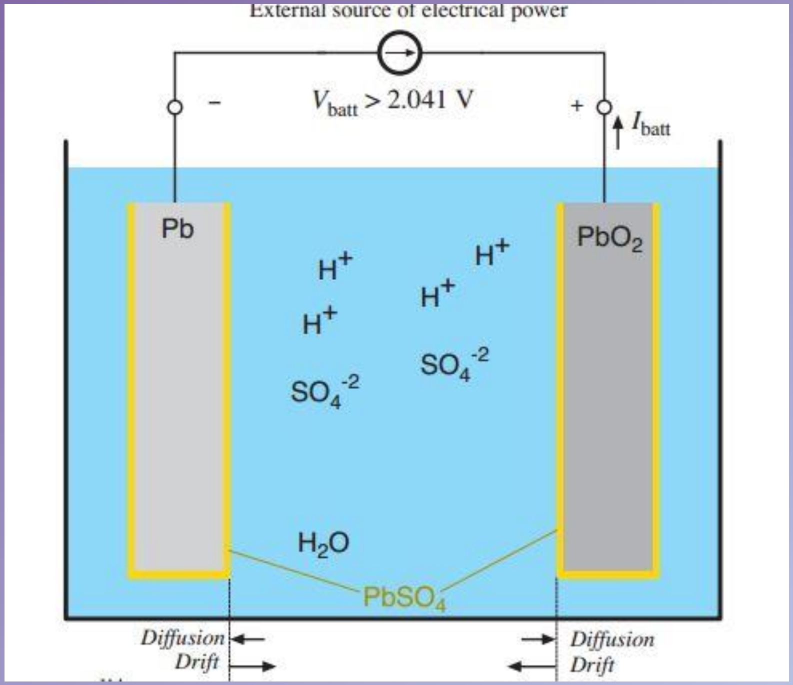
Discharge


R
−
$V_{batt} < 2.041$ V
+
I_{batt}
Pb
PbO_2
H^+
H^+
H^+
H^+
SO_4^{-2}
SO_4^{-2}
H_2O
$PbSO_4$
Diffusion
Drift
Diffusion
Drift

Charge

- Connection of an electrical power source forces electrons to flow from positive to negative terminals
- This increases the charge and the voltages at the electrodes
- The chemical reactions are driven in the reverse direction, converting electrical energy into stored chemical energy
- As the battery is charged, the lead sulfate coating on the electrodes is removed, and the acid electrolyte becomes stronger

Charge



External source of electrical power
$V_{batt} > 2.041$ V
−
+
I_{batt}
Pb
PbO_2
H^+
H^+
H^+
H^+
SO_4^{-2}
SO_4^{-2}
H_2O
$PbSO_4$
Diffusion
Drift
Diffusion
Drift

State of charge

- State of charge can be determined by terminal voltage
  - There are caveats, internal impedance, other tests
- Terminal voltage should be measured 1 hour after removal from charger (at rest)
- Terminal voltage should be measured with no load

State of charge

	Fully Charged	Completely Discharged
State of charge:	100%	0%
Depth of discharge:	0%	100%
Electrolyte concentration:	~6 molar	~2 molar
Electrolyte specific gravity:	~1.3	~1.1
No-load voltage:	12.7 V	11.7 V

(specific battery types may vary)

Killing your batteries

- Over discharging
  - Beyond 20% for starting battery
  - Beyond 50% for deep cycle
  - Leaving a battery discharged
    - Sulfate on plates becomes harder over time
      - Insulates plate so that chemical reaction cannot continue
  - Freezing
    - Happens more easily at discharge due to electrolyte being mostly water
  - Over Charging
    - Electrolysis of water
    - Boiling out

Killing your batteries

- A word on discharge
  - Typical lead acid will lose 5% of charge per month at rest
  - Self discharge rate increases with temperature
    - Approximately doubles for each 18 degrees F
  - Battery needs to be replaced if 30% of charge is lost in first 24 hours at rest

Understanding Capacity

- Measured in Amp/Hours
  - Accompanied by “C” rating
- “1C” is constant current draw level that will discharge battery from full to empty in 1 hour
  - More typically found on Lithium batteries, but nearly all chemistries have a published “C” rating.
- Although Amp/Hour is actual capacity, “C” is typically used to describe max charge and/or discharge rate

Understanding Capacity

- Automotive batteries are usually listed in RC
  - Reserve capacity (Time battery can run at 25 amps without dropping below 10.5 volts)

To convert to a more useful Amp/Hour:

- Multiply RC by 60 (convert to seconds)
- Multiply by length of time in RC (which is 25)
  - This gives you Coulombs of Charge
- Divide this by 3600 (Number of Coulombs in an Amp Hour)
      - » RC * 60 / 25 = CC / 3600 = AmpHour

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Understanding Capacity

- Example – Interstate SRM-27
  - RC = 160

- 160 * 60 = 9600 (seconds)
- 9600 * 25 = 240,000 (Coulombs)
- 240,000 / 3600 = 66.6 AmpHour

Understanding Capacity

- “1C” is 1 hour discharge, so “2C” would be the current draw to discharge entirely in 30 minutes, while “0.5C” would be a 2 hour discharge current rate (etc…)
- Peukerts law – removes some capacity

Understanding Capacity

For a one-ampere discharge rate, Peukert's law is often stated as:

$$C_p = I^k t$$

where:

- C_p is the capacity at a one-ampere discharge rate, which must be expressed in A·h.
- I is the actual discharge current (i.e. current drawn from a load).
- t is the actual time to discharge the battery, which must be expressed in h.

The capacity at a one-ampere discharge rate is not usually given for practical cells. It is useful to reformulate the law to a known capacity and discharge rate:

$$t = H\left(\frac{C}{IH}\right)^k$$

where:

- H is the rated discharge time, in (hours).
- C is the rated capacity at that discharge rate, in (Ampere-hours).
- I is the actual discharge current, in (Amps).
- k is the Peukert constant, (dimensionless).
- t is the actual time to discharge the battery, in (hours).

Using the above example, if the battery has a Peukert constant of 1.2 and it is discharged at a rate of 10 amperes, it would be fully discharged in time $20\left(\frac{100}{10 \cdot 20}\right)^{1.2}$ which is approximately 8.7 hours. It would therefore dispense only 87 ampere hours rather than 100.

Understanding Capacity

- Easier rule of thumb
  - 80% of rated Amp/hr

Understanding Capacity

- Batteries will not deliver as much energy at higher “C” rates.
- Lead acid often rated at C/10

Nominal capacity: A-hrs @ 25˚C to 1.75 V/cell				
1 hr	2 hr	4 hr	8 hr	24 hr
36 A-hr	45 A-hr	46 A-hr	49 A-hr	56 A-hr

Understanding Capacity - Sidetrack

- Why do you care?
  - Amp/hr capacity is important in calculating how long your battery will run your equipment.
  - So how do you figure out what you need?

Understanding Capacity - Sidetrack

- Simple calculation.
  - Measure transceiver TX current draw
  - Measure RX current draw
  - Estimate time TX vs. RX
    - If you are NOT a net control, 80% RX and 20% TX good rule of thumb
    - If you ARE a net control, 50-50 is a better number

Understanding Capacity - Sidetrack

- If your transceiver draws 12 amps on transmit and 1 amp on receive, you need (if not NCS) 12 amps * 12 minutes (20% of an hour) and 1 amp * 48 minutes (80% of an hour) = 192 Amp/minutes or (divide by 60) 3.2 Amp/hours.
- If you operate for an 8 hour shift, take 3.2 Amp/hours * 8 hours = 25.6 Amp/hours.
- Peukerts law says use 80% of capacity so you need 30.7 amp hour battery
  - If you calculate everything on “High” power, you’ll be covered for your shift using any power level.

Charging

- Several types of chargers out there
  - Bulk charger (Typical charger, might even include "Float" Often marked as "Automatic")
  - 3 State charger
  - Desulfator

Charging

- 3 state charging is imperative to maintaining lead acid battery health.
  - Bulk charge (Charges to 80%)
  - Absorption charge (Charges last 20%)
  - Float/Maintain (Keeps battery at 100%)

Charging

- Bulk charge:
  - Charges to 80% (Constant current, voltage is measured)
  - Smart chargers will start at a low fixed current, then step to a larger current so as not to damage a very heavily discharged battery.
  - Charger watches terminal voltage of battery to determine level of charge

Charging

- Absorption charge:
  - Charges from 80% to 100%
  - Is much slower rate of charge than bulk
  - Constant voltage (often high, up to 15+ volts)
    - Caution: Never use a charger over 15 volts with Gel chem!
  - Measures current to determine battery charge level

Charging

- Float/Final/Maintenance charge:
  - Current limited (to a very small current, typically 10 % of the bulk charge rate, if battery needs more than that, it drops back to bulk mode and starts over)
  - Delivers ONLY as much charge as battery requires
    - Charger must be capable of delivering ZERO amps.

Charging

- Battery charge rate/capacity will change based on temperature
  – High quality chargers will temperature compensate.

Charging - Desulfation

- As mentioned earlier, discharged batteries, or batteries left sitting at low charge will have Sulfate built up on plates.
- Desulfating chargers will pulse DC, or output low current AC for small periods of time to “knock off” the sulfate.
- Sulfate falls to bottom of battery, if not too thick, will recombine into electrolyte.
- Some “smart” chargers will do this occasionally just to keep any sulfate from building.
- Is not an “end all” solution, only works on light sulfation.
  - Physically shaking a battery being desulfated can accelerate
- Better answer is to take good care of your battery and not left it sulfate!!!

Chargers

- Chargers I have experience with:
  - A&A Engineering
  - NOCO
  - Npower
  - Optima
  - Battery minder
  - Battery tender
  - Anything based on UC2906 by Unitrode

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Chargers


G15000
15A (15000mA)
MODE
25%
50%
75%
100%
12V 15A
NORM COLD/AGM
24V 7.5A
NORM COLD/AGM
12V
13.6V
REPAIR 1.5A
SUPPLY 5A
12V 15A
AGM
12V 15A
LITHIUM
JUMP CHARGE
20A
5 MIN

Lead Acid Batteries – In Summary

- Keep your batteries on a “smart” 3 stage charger at all times
- Use them once in a while
- If possible, load test them once a year
  - Will they produce what you think they will?

Lead Acid Batteries – In Summary

- A quick note on load testing
  - There are several good devices on the market to do this
    - West Mountain CBA IV
  - You can also use a car headlight!
    - Watch voltage closely

Lead Acid Batteries – In Summary

Lead Acid Batteries – In Summary

- Taking good care of your batteries with a small investment in charging/monitoring technology will save you big in the end!
- Remember that batteries are heavy and full of acid, just be careful!

Break

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Lithium

A whole new world……

A whole new set of Pros and Cons….

You may notice, this section will have a lot of emphasis on

SAFETY!!!

First, some basics of Lithium Ion

Lithium ions (Li^+) are involved in the reactions driving the battery. Both electrodes in a lithium-ion cell are made of materials which can intercalate (absorb) lithium. Intercalation is when charged ions of an element can be 'held' inside the structure of a host material without significantly disturbing it.

In the case of a lithium-ion battery, the lithium ions are tied to an electron within the structure of the anode. When the battery discharges, the intercalated lithium ions are released from the anode, and then travel through the electrolyte solution to be absorbed (intercalated) in the cathode.

First, some basics of Lithium Ion

- As the battery is charged, an oxidation reaction occurs at the cathode, meaning that it loses some negatively charged electrons.
- To maintain the charge balance in the cathode, an equal number of some of the positively charged intercalated lithium ions are dissolved into the electrolyte solution.
- These travel over to the anode, where they are intercalated within the graphite. This intercalation reaction also deposits electrons into the graphite anode, to ‘tie’ up the lithium ion.

First, some basics of Lithium Ion

- During discharge, the lithium ions are de-intercalated from the anode and travel back through the electrolyte to the cathode.
- This also releases the electrons that were tying them to the anode, and these flow through an external wire, providing the electric current that we used to do work.
- It's the connection of the external wire that enables the reaction to proceed—when the electrons are free to travel, so are the positively charged lithium ions that will balance the movement of their negative charge.

First, some basics of Lithium Ion

- The transfer of lithium ions between the electrodes occurs at a much higher voltage than in other battery types and, as they must be balanced by an equal amount of electrons, a single lithium-ion cell can produce a voltage of 3.6 volts or higher, depending on the cathode materials.

- A typical alkaline cell produces only around 1.5 volts.

First, some basics of Lithium Ion

- The anode is usually graphite.
- However, the repeated insertion of lithium ions into the standard graphite structure in a typical lithium-ion battery eventually breaks apart the graphite.
- This reduces the battery’s performance and the graphite anode will eventually break down, and the battery will stop working.

Some common variants

- LiPo (Lithium Polymer)
  - Your typical RC car/plane/Drone battery. Solid electrolyte makes battery slightly safer than liquid, but often contained in soft, flexible pocket material making it prone to puncture.

- $LiFePO_4$ (Lithium Iron Phosphate)
  - Higher discharge rate capable because of higher temperature coefficients. Better thermal stability. Longer life cycle, but faster self-discharge rate.

- $LiMn_2O_4$ (Lithium Manganese Oxide)
  - Another variant that improves safety, but has lower capacity and shorter overall lifetime.

- $LiNiMnCoO_2$ (NMC) (Lithium Nickel Manganese Cobalt Oxide)
  - Nickel changes the game. Higher current flows (burst) are available, longer life, and longer overall capacity is achieved. Most electric vehicle batteries are this type. Most expensive to manufacturer.

LiPo energy density is significantly higher than other chemistries.

It's lighter, smaller.

It can discharge at far higher rates.

No "memory" problems as NiCd,NiMh have.

So, what's the catch?

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Some other “Cons”

- Safe containment needed to charge, discharge, and store.

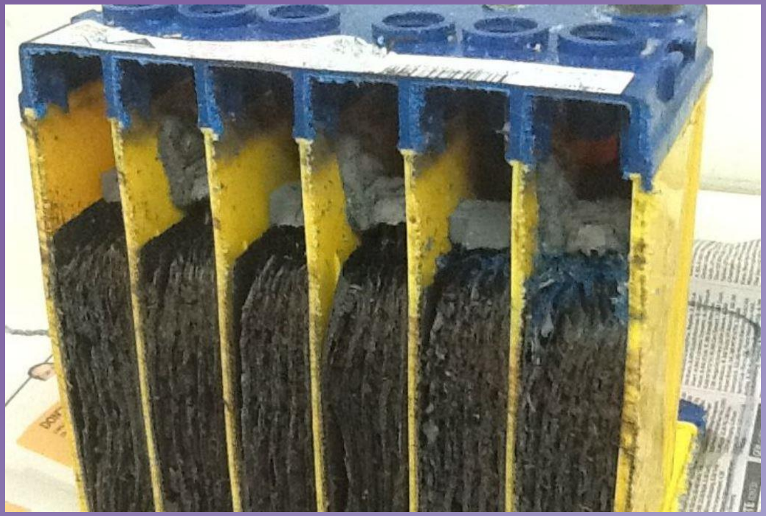
- Shorter life
  - Less cycles, less shelf life (couple hundred cycles compared to 1000+)

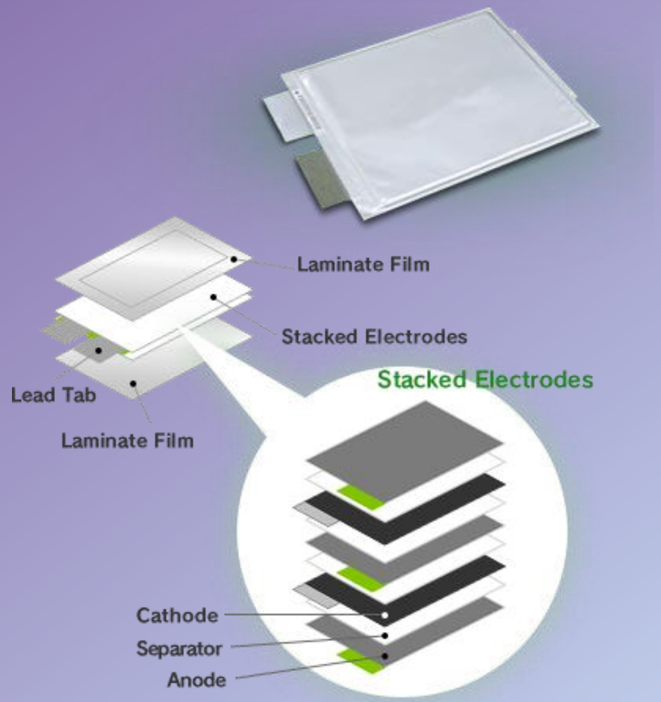
- Must store at reduced charge
  - Fully charged batteries “eat” themselves

- Must charge with dedicated and special charging equipment
  - Charging Lithium with Lead acid, NiMh chargers can cause explosion!

- Must “balance” packs, and maintain balance for safety

Let’s look at the differences





Lithium

- Higher power density
  - Lighter/Smaller
- Higher discharge rate
- Slower re-charge rate
- Specialized charger needed
- Storage at less than 100% charge needed
- Need to "Balance" cells in pack
- Shorter lifetime
  - Less charge/discharge cycles
- MUCH higher safety considerations
  - Puncture
  - Temperature
  - Short circuit prevention

SLAB/NiMh/NiCad

- Lower power density
  - Heavier/Larger
- Lower discharge rate
- Faster re-charge rate
- No specialized charger needed
- Storage at 100% charge best
- No need to "Balance" cells
- Longer lifetime
  - More charge/discharge cycles
- Lower safety considerations
  - Acid
  - Short circuit prevention (To extent)

Key terminology

- Lead acid nominal voltage is 2 volts per cell.

- Batteries do not typically advertise number of cells, only nominal voltage.
  - Example:
    - Car battery is (6) cells in series @ 2 volts = 12 Volt battery

- Nickel based batteries are 1.25volts per cell
  - Example:
    - Toy game uses (4) cells in series @ 1.25 volts = 5 volt battery

Key terminology

Lithium Chemistries usually list “S” count instead of voltage.
Each “S” is a single Cell

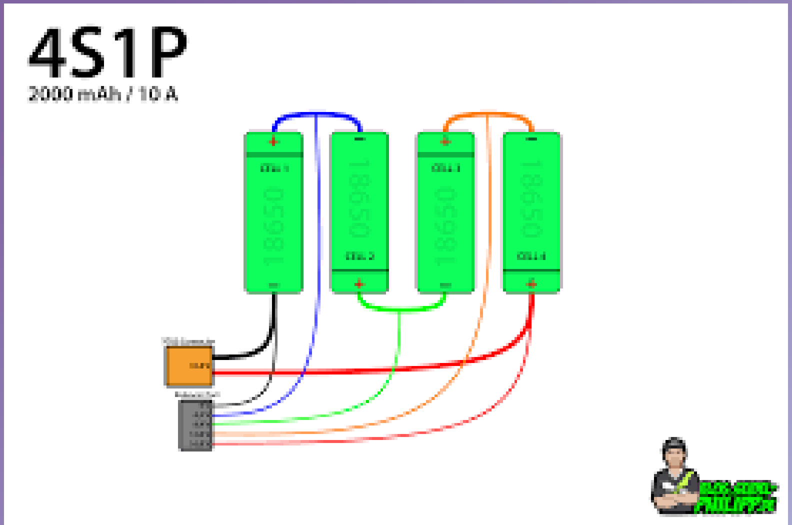
LiPo nominal voltage is 3.7 volts per cell.
Example:
(4) Cells in series @ 3.7 volts = 14.8 volts

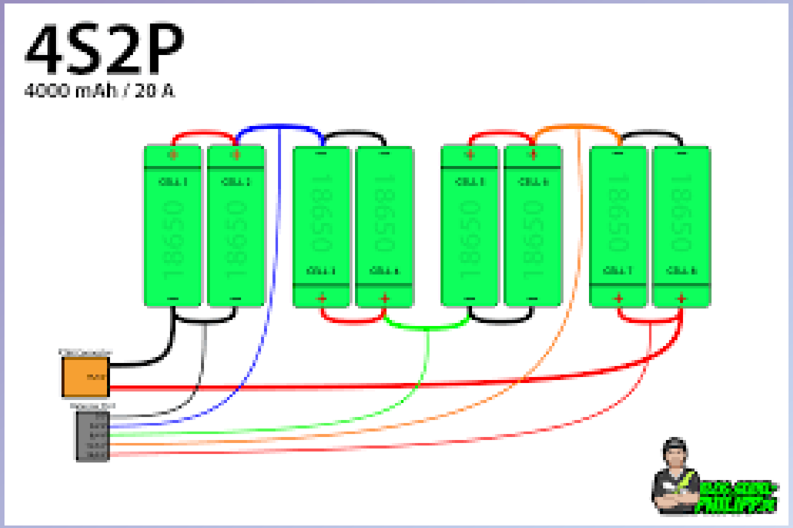
LiFePO4 nominal voltage is 3.3 volts per cell
(4) Cells in series @ 3.3 volts = 13.2 volts

Key terminology

You may see batteries listed with both “S” and “P” designators

Example: 4S1P or 4S2P





Don’t fall for the “nominal” trap!!!

Nominal simply translates to “Named” and is used to place a battery in a voltage “Class”

Let’s take the LiPo example:

LiPo nominal voltage is 3.7 volts per cell.
Example:
(4) Cells in series @ 3.7 volts = 14.8 volts

Don’t fall for the “nominal” trap!!!

Real life:
Fully charged LiPo cell = 4.3 Volts
(4) Cells in series @ 4.3 volts = 17.2 volts! (This is a 4S battery)
(3) Cells in series @ 4.3 volts = 12.9 volts

Neither of those are friendly numbers for typical 12 volt devices

More friendly solution: $LiFePO_4$

Real life:

Fully charged $LiFePO_4$ cell = 3.6 Volts
(4) Cells in series @ 3.6 volts = 14.4 volts (This is a 4S battery)

The mysterious 13.8 V

Now that you know the difference between Nominal voltage and Full Charge voltage, the lead-acid numbers make sense:

“12” volt battery is (6) 2 volt cells in series,

Real life:
Fully charged lead acid cell is 2.3 volts per cell * 6 cells = 13.8 Volts

Charging considerations

Charging considerations

Types of charging for Lithium chemistries:

- “Fast” charge
  - Charges at very high C rate, takes cells through ONLY first charge phase (Constant Current) and gets pack to ~80% quickly
- “Normal” charge
  - Charges at typical C rate (1C), takes cells through all 3 or 4 charge phases. Gets pack to 100% and maintains, takes longer.
- “Balance” charge
  - Same type of charge as “Normal” but places a small load across each individual cell while charging to make sure every cell gets to the exact same voltage/charge level at the end of the process.

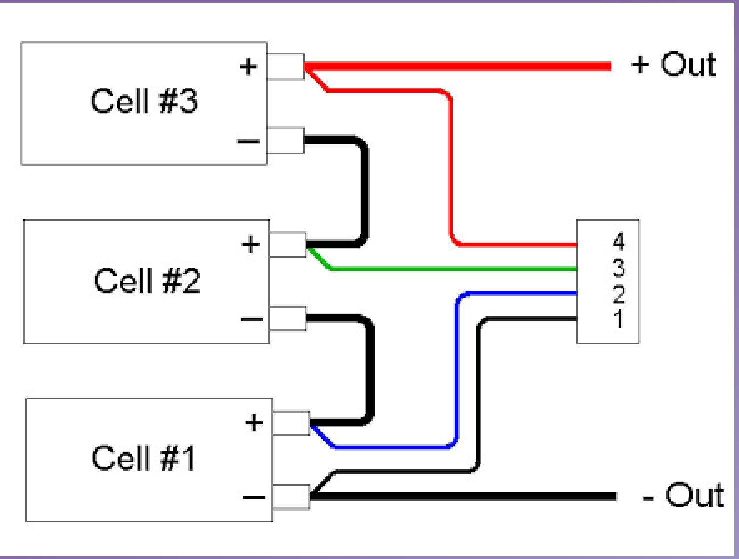
Importance of balance charge

Charger monitors each cell voltage from beginning to end of process.

If one cell fails, because of the very high discharge capabilities of Lithium, the other cells could very rapidly dump energy into the “dead” cell and cause:

- Fire
- Pack failure (and the load to which is connected to it)
- Early pack self-discharge

Importance of balance charge



Importance of balance charge

Sidenote – Cell protection

Protection Circuit Module (PCB) for 3.7V Li-ion (18650/18500) cell Battery (2A Limit) with NTC

See Reviews

Your Price: $1.90

In Stock

Product ID # 853
Part Number: PCB-S1A2BK10

Quantity: 1 Buy

Add to a new shopping list

Email this page to a friend

Sidenote – Cell protection

Have we mentioned safety?

Lithium batteries have special safety considerations

- They must be treated carefully during Charge, Storage, and Discharge
- Batteries can fail at any time, complacency in this area could result in loss of life or property!

This happened to a fellow Colorado Ham at 4am.
A fully charged battery just sitting idle.

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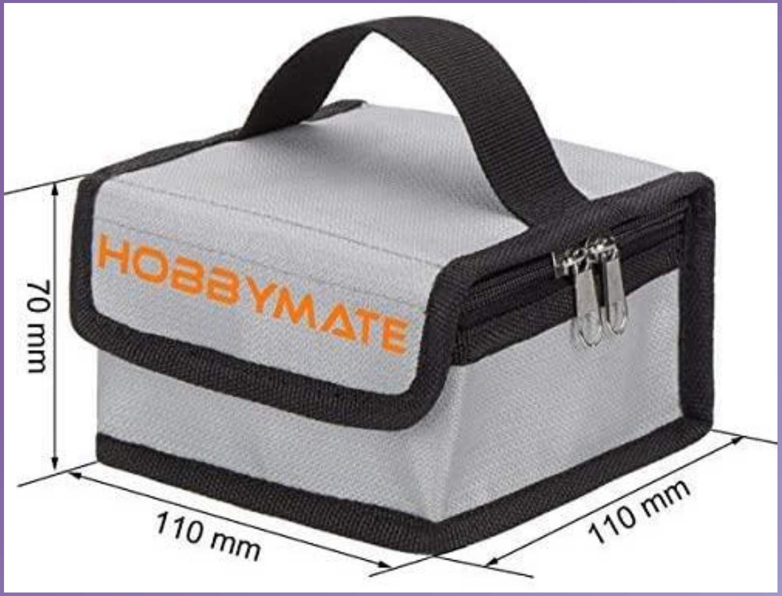
And he reminds us that having one of these is what saved his home and possibly his life!!

Charging / storage safety



Charging safety

Charge bag picture

Charging safety

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Charging safety

Storage safety

Nothing above to catch on fire.

Vented

Raised from floor
(Heat)

Caution: Don’t pinch wires!

Storage safety

Lots of conflicting info on storage voltage, but all agree it's less than 100%

Generally accepted standards:

- 3.8 Volts for LiPo
- 3.3 Volts for LiFePO4

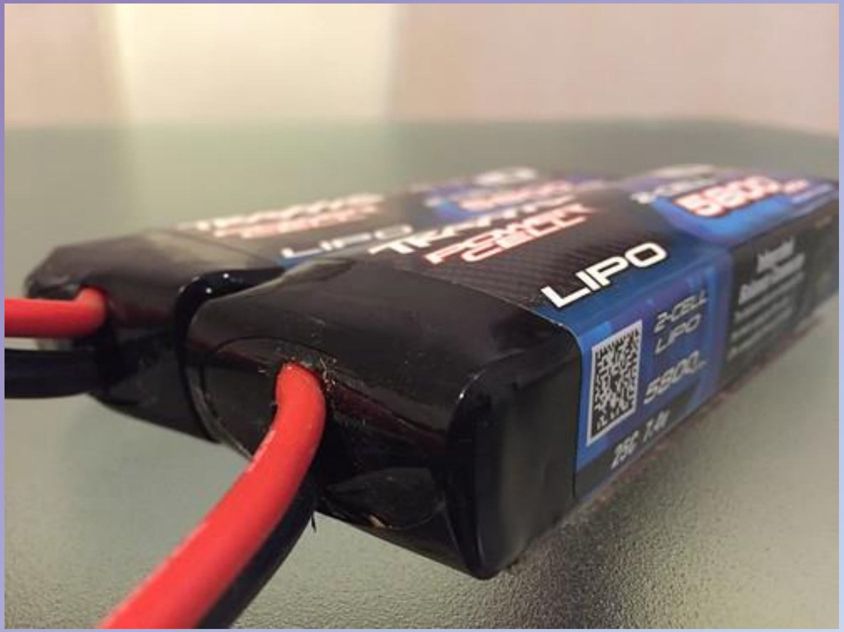
Generally, aim for somewhere between 40~60% of full for storage

- NEVER store at 100%
- NEVER store at or near depleted

- Aim to store them at room temperature. Too hot or cold depletes life.
- Because room temperature is recommended, that typically indicates you'll be storing them IN your home. Even more reason to heed the safety warnings!

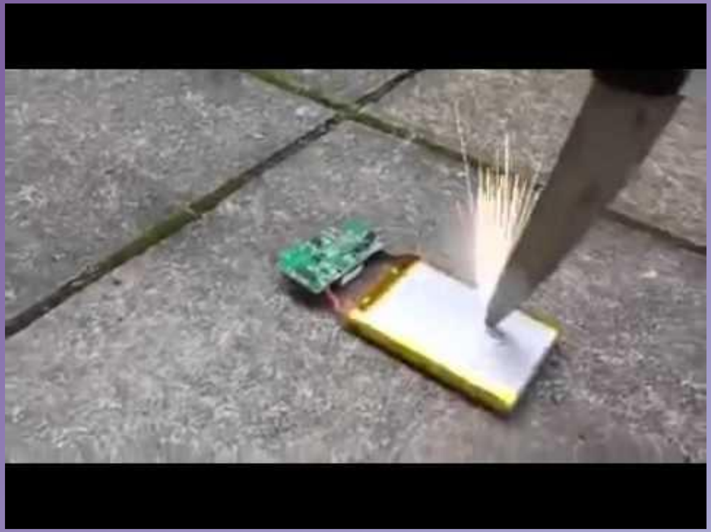
Storage safety

Safely recycle when ANY battery shows swelling!
Transport only in fire safe container!

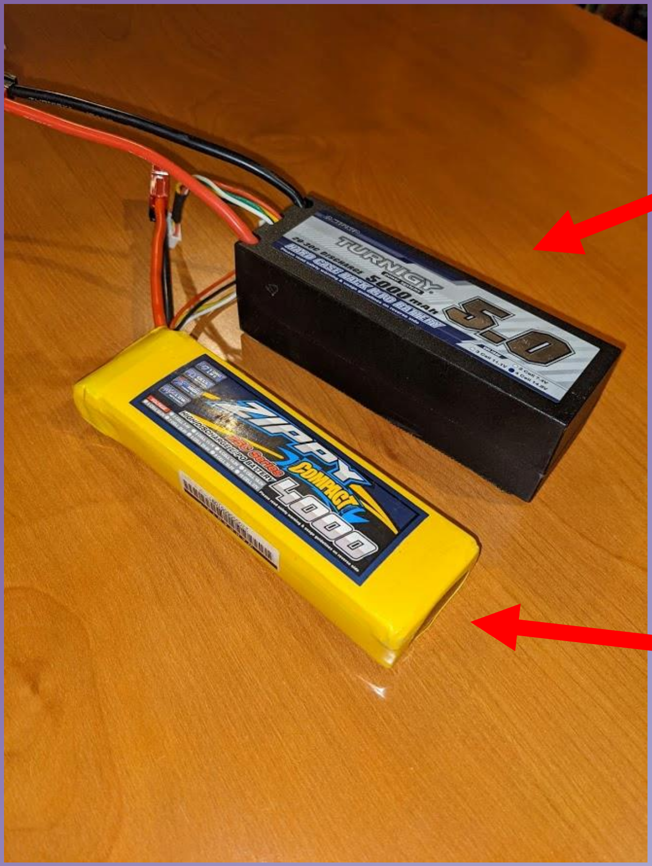


Storage safety

Be careful of puncture and shorting hazard!



Storage safety



Hard case LiPo can provide additional protection when battery is in environment that cannot guarantee its physical safety

Shrink wrap LiPo relies on outside environment for safety

Discharge procedures and safety

Lithium batteries should be stored partially discharged to prolong their life.

But…..

Lithium have far fewer charge/discharge cycles before they need to be replaced

So….

You must find a balance between estimate of when you will need them again and how quickly you are willing to replace them

Discharge procedures and safety

The numbers vary, but here's a reasonable estimate for degradation of a fully charged LiPo:

- Loses 20% of it's capacity in a year if fully charged and kept at room temperature

- Loses 40% of it's capacity in 3 months if fully charged and kept at 140 degrees (so don't store batteries in your car in the summer!!)
    - Don't store them cold either, although no damage will occur, it's unsafe to charge them back up if they are cold!!

- A good rule of thumb: If it's going to sit idle for more than 2 weeks, discharge to storage voltage!

Discharge procedures and safety

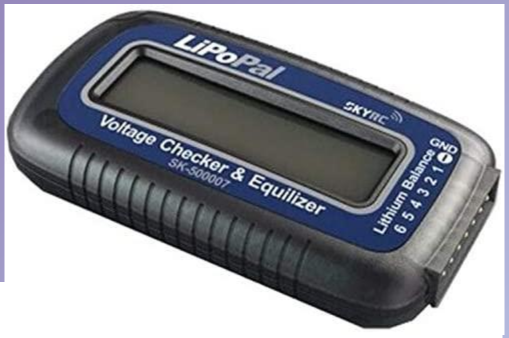
- Some advice: A Lot of Lithium chargers (especially those for the Radio Control Model Market) advertise they can discharge also.

- Don't use them for discharge!

- They often use the same transistors that switch the charge current for discharge which are often undersized for discharge currents.
  - Instead of proper wire-wound resistors for a load, they PWM switch the battery to ground to discharge which generates a tremendous amount of heat on the transistor.
    - They will fail prematurely at an alarming rate!

Discharge procedures and safety

- Use a discharge device designed for discharge!



Discharge procedures and safety

- Best to use a discharger that can balance cell voltage
  - OK to use mass discharger to get close, then balance to final voltage
- Be very careful not to over-discharge!
  - A single over-discharge can destroy battery permanently!
- Just like charging, don't leave it unattended
  - Make sure to discharge in a fire/explosion proof container
- Use a reasonable discharge rate
  - Just because the battery is rated for 35C or 50C discharge doesn't mean you should use that!

Discharge procedures and safety

Example:

- 5000 mAh battery is rated @ 50C
- 5000 mAh = 5 Amp/Hour
- 5 * 50 = 250 amps!!!

Don't do this! You'll overshoot!

A more reasonable approach:

- Discharge at 5 amps until close, then balance discharge (usually 50 mAh) to final.

Thank you!!

73 de KI0KN